A surface energy budget approach to understanding the CMIP5 inter-model spread in Arctic Amplification

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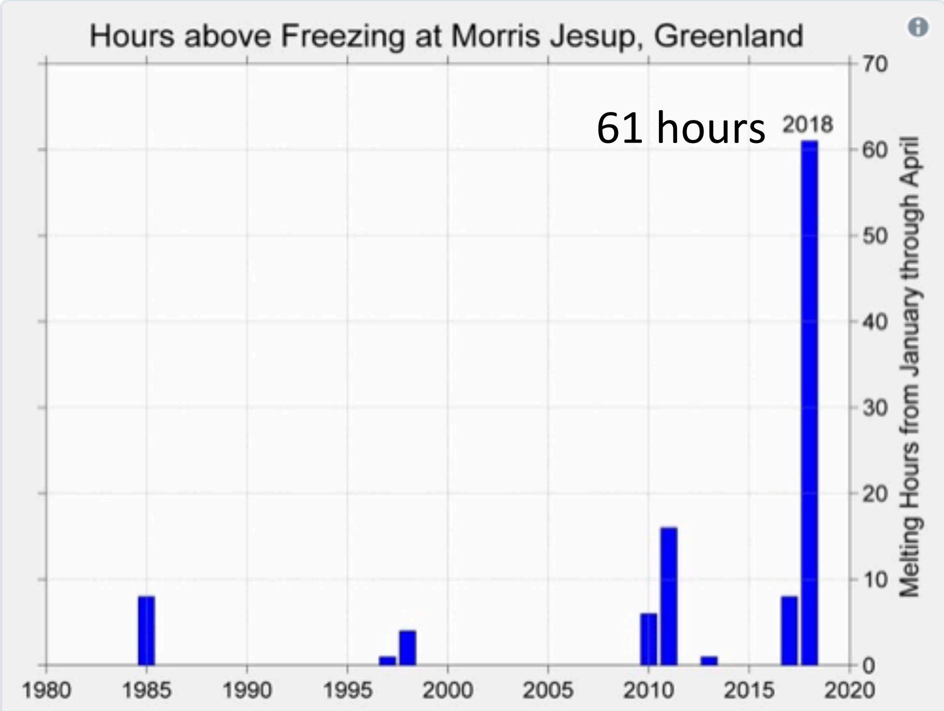


Robert Rohde
@rarohde

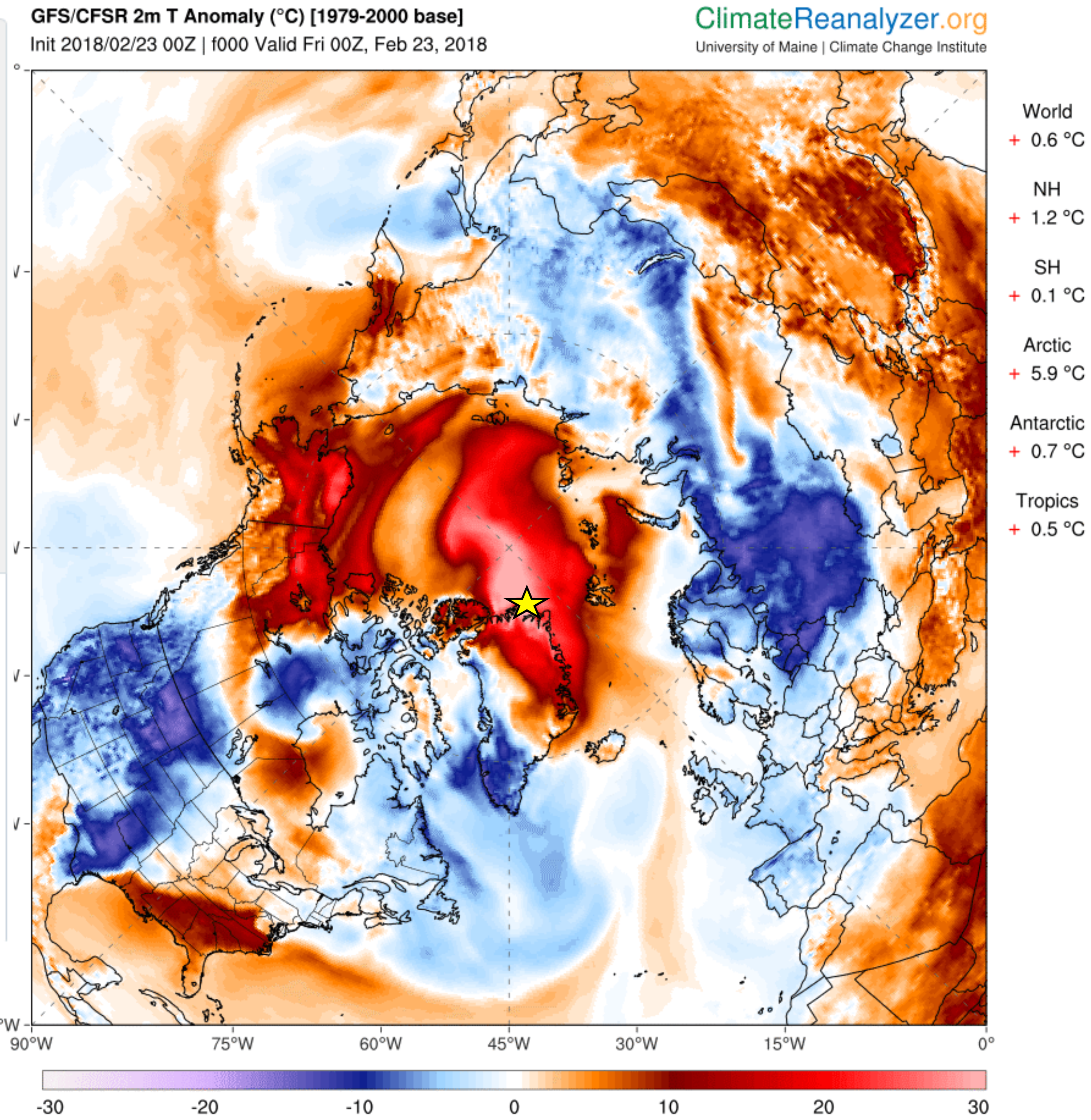
Replying to @rarohde

In 2018, there have already been 61 hours above freezing at Cape Morris Jesup, Greenland.

The previous record was 16 hours before the end of April in 2011.

8:02 PM - Feb 25, 2018

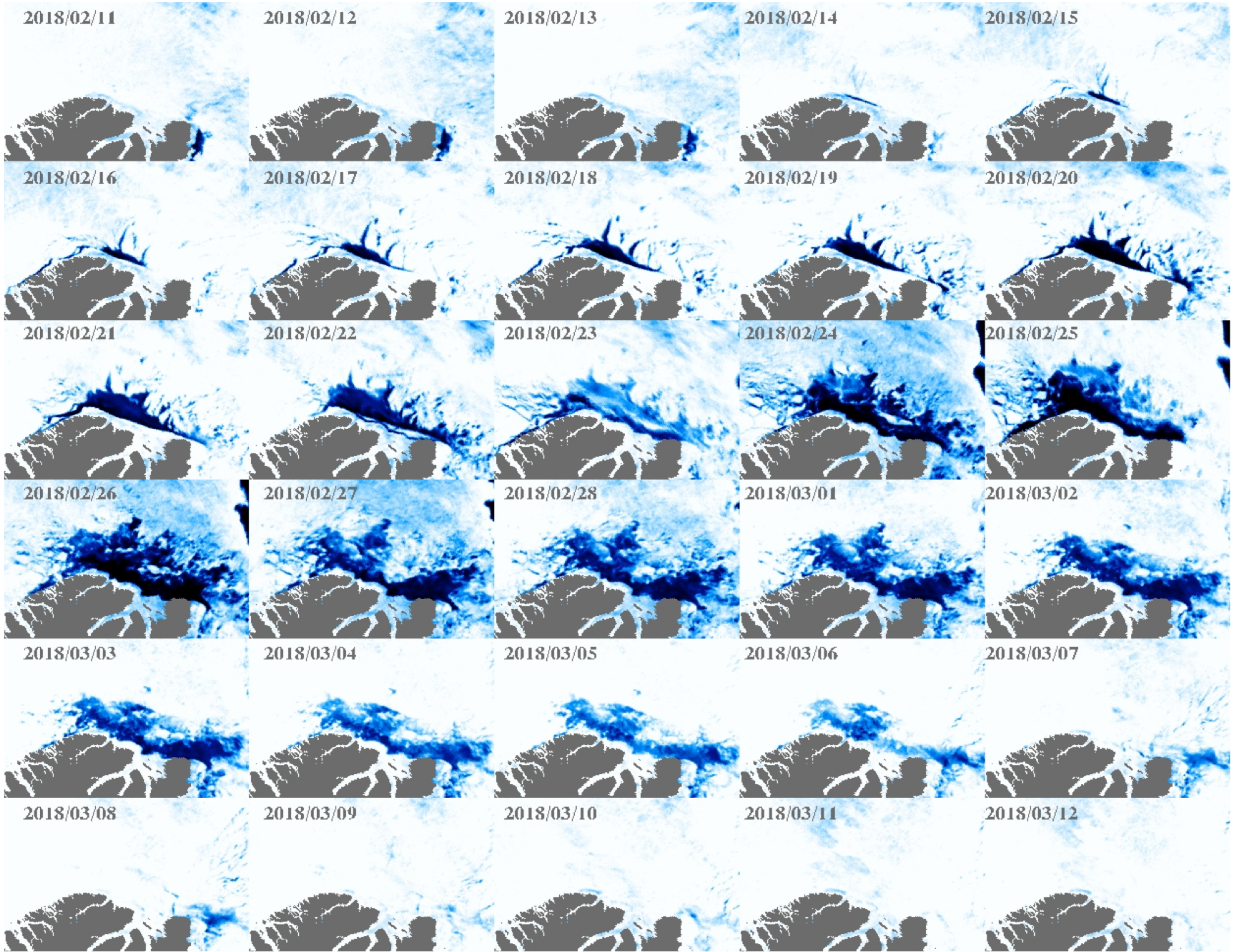
157 180 people are talking about this



Source:https://www.theweathernetwork.com/

Associated rare polynya:
Lasting more than 3 week.

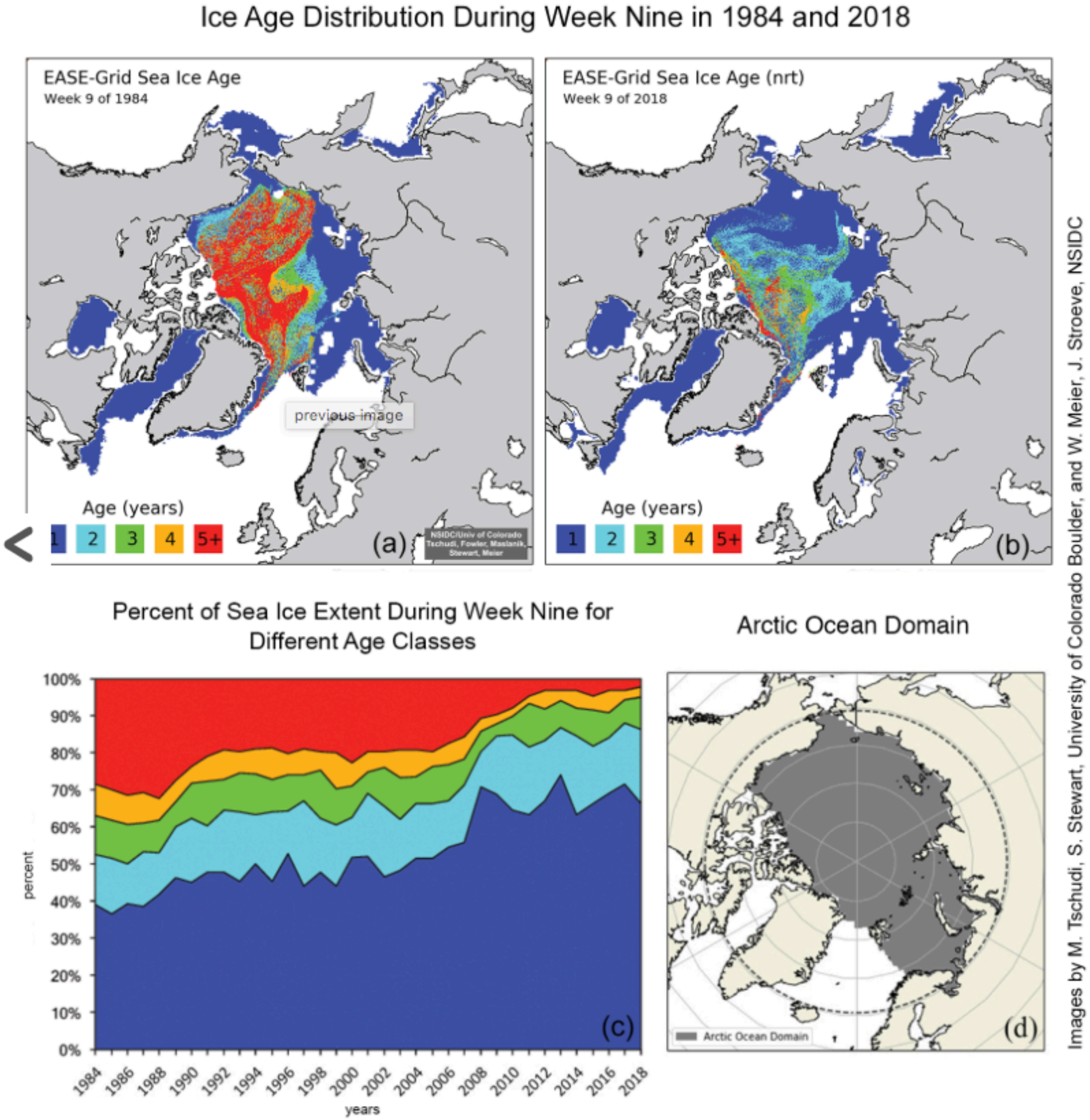
Sequence Images of Polynya Opening North of Greenland
Feb 11, 2018 to March 12, 2018



J. Stroeve, National Snow and Ice Data Center

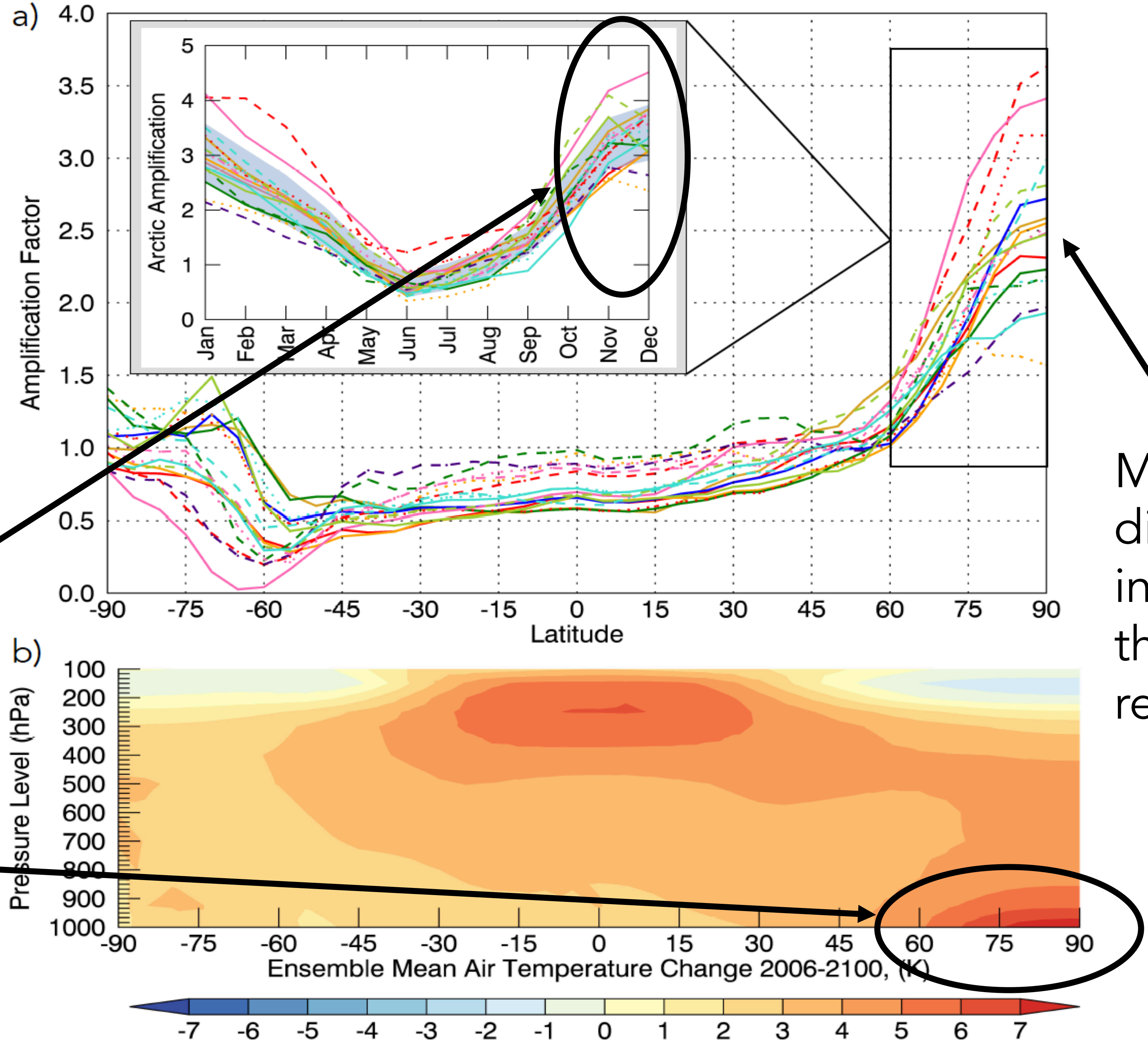
Transformation form multi-year to first-year sea ice.

Arctic sea ice cover continues to decline.



Source: NSIDC

Nature of Arctic Amplification



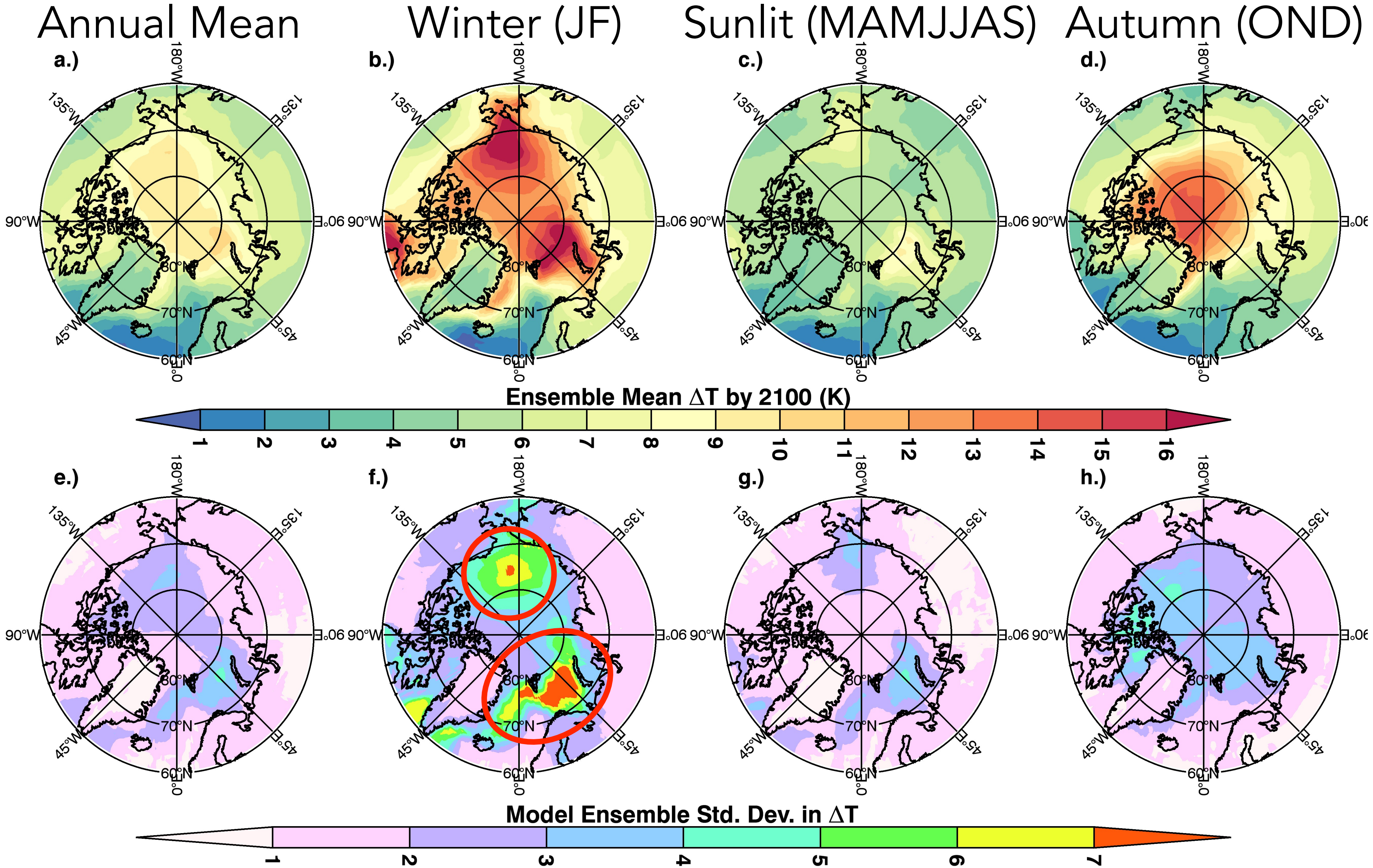
Most warming in fall/winter

More model disagreement in the Arctic than any other region

Bottom heavy warming profile

Where and when do CMIP5 model differ on Arctic warming projections?

Largest differences between CMIP5 models occur in fall and winter in the Barents-Kara Seas and the Chukchi-Beaufort Seas regions.



Boeke and Taylor (in revision)

Method: Surface energy budget decomposition

Lu and Cai (2009)

Surface energy budget Eq.:

$Q = (1-\alpha)S\downarrow sw\ down + F\downarrow lw\ down - \varepsilon\sigma T\downarrow s\uparrow 4 - (S+L)$

Rewriting using clear-sky fluxes and cloud radiative effects and solving for ΔTs

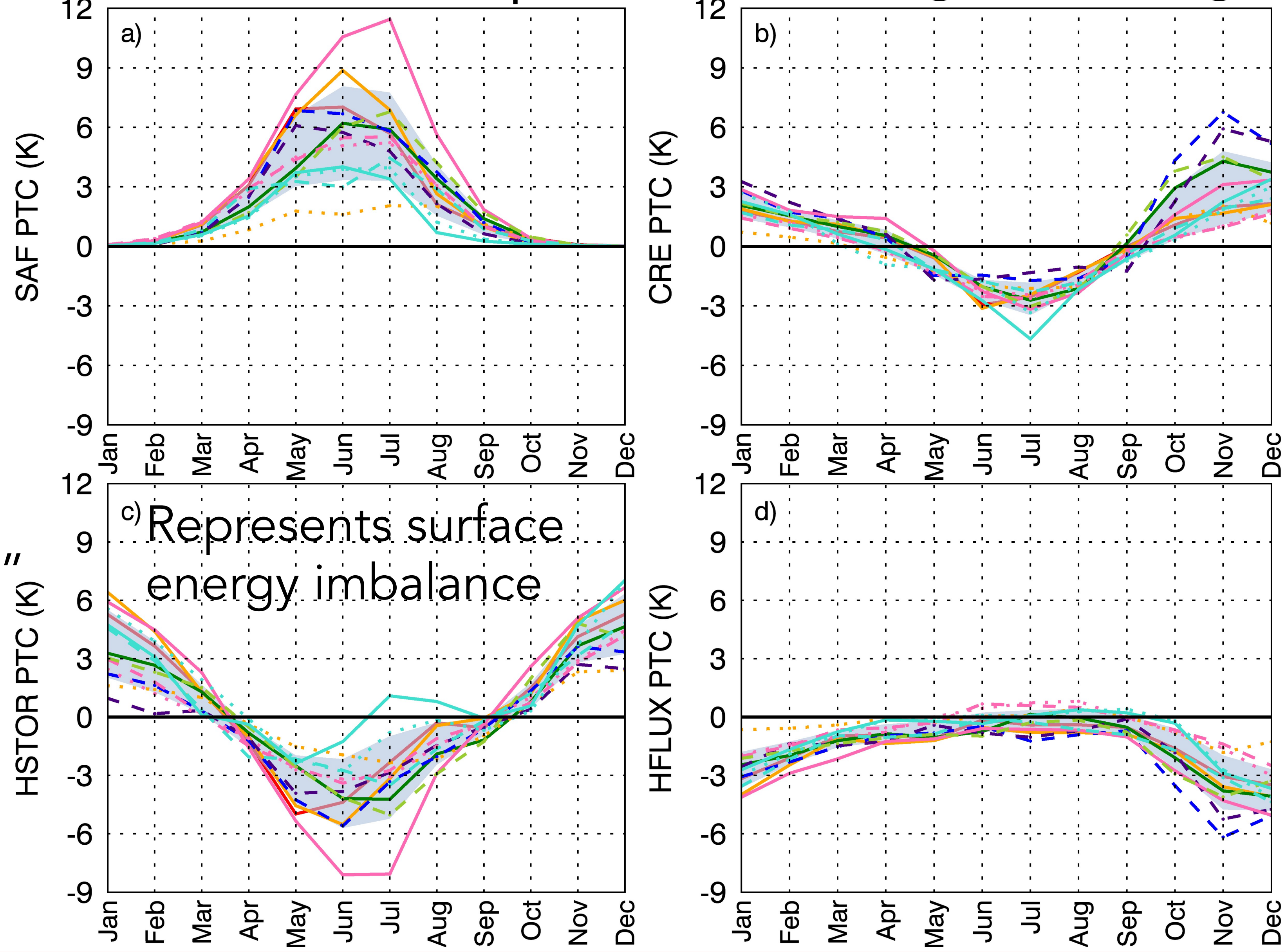
$\Delta Ts =$ (the sum of)

FEEDBACK	PTC (K)	ANNUAL MEAN (K)
Surface Albedo Feedback (SAF)	$\frac{-(\Delta\alpha)(\overline{S\downarrow} + \Delta S\downarrow)}{4\sigma\overline{T_s^3}}$	1.82 ± 0.77
Cloud Forcing (CRE)	$\frac{(1-\alpha)\Delta S\downarrow_{CLD} + \Delta F\downarrow_{CLD})}{4\sigma\overline{T_s^3}}$	0.69 ± 0.88
non-SAF shortwave clear-sky feedbacks	$\frac{(1-\alpha)\Delta S\downarrow_{CLR}}{4\sigma\overline{T_s^3}}$	-0.43 ± 0.20
Longwave clear-sky feedbacks (LWCS)	$\frac{\Delta F\downarrow_{CLR}}{4\sigma\overline{T_s^3}}$	7.27 ± 1.4
Change in ocean heat storage (HSTOR)	$\frac{-\Delta Q}{4\sigma\overline{T_s^3}}$	-0.30 ± 1.2
Change in latent and sensible heat fluxes (HFLUX)	$\frac{-\Delta(S+L)}{4\sigma\overline{T_s^3}}$	-1.67 ± 0.86

LW clear-sky feedbacks dominate the Arctic warming signal.

Contributions to surface temperature change--Strong seasonality

SAF strongly warms surface in summer.



Clouds cool surface in summer and warm in fall/winter.

HSTOR “cools” surface in summer and “warms“ surface in summer.

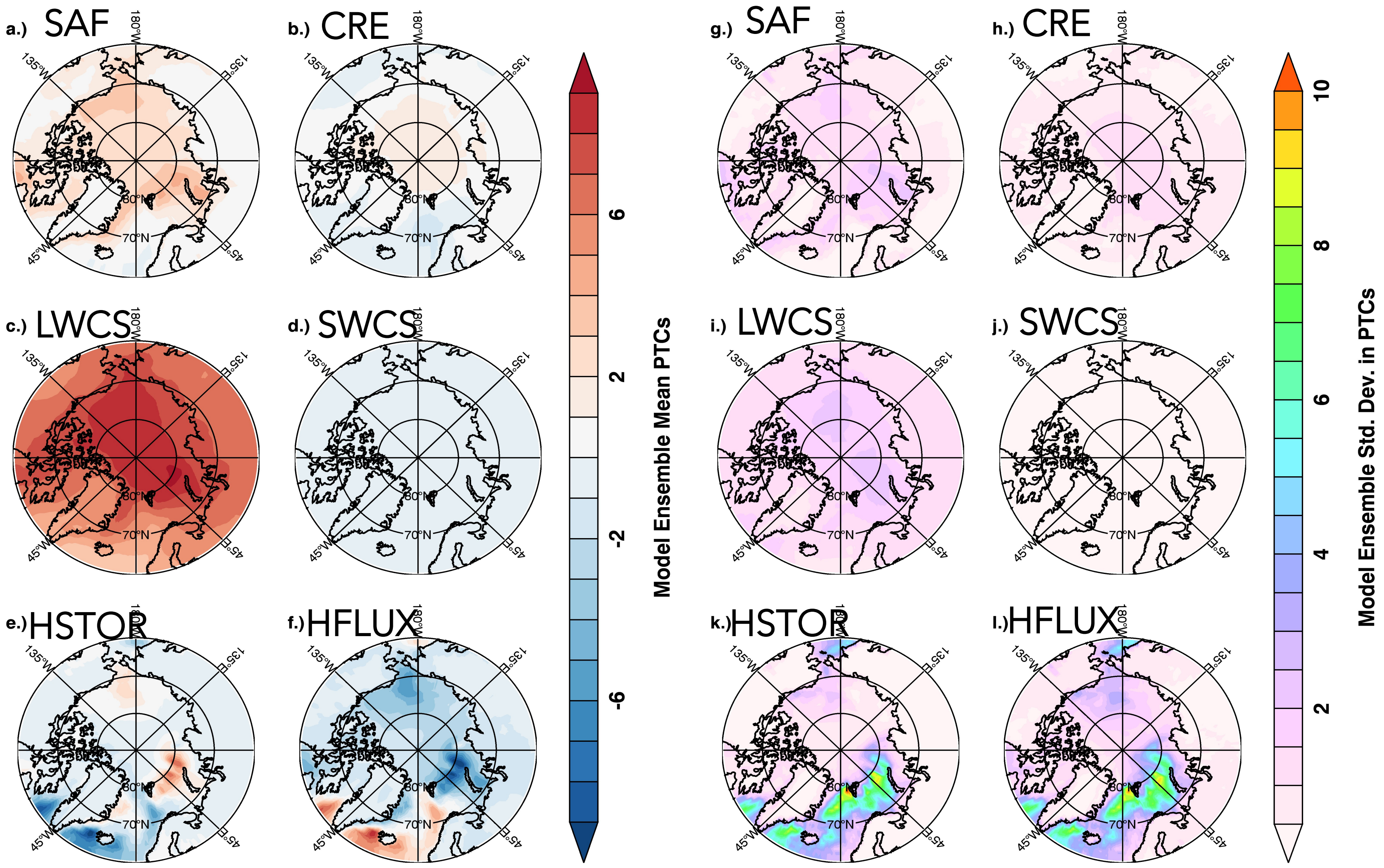
HFLUX show no change in summer and cool surface in fall/winter.

The seasonality of these contributions is amazingly consistent across models.

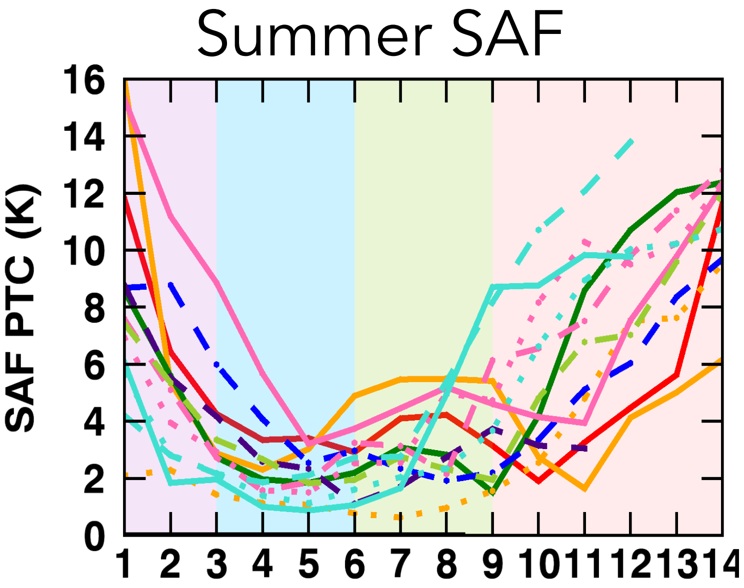
How are the model differences spatially distributed?

Radiative feedback spread=>spatially uniform

Surface non-radiative feedback spread=> regionally-focused

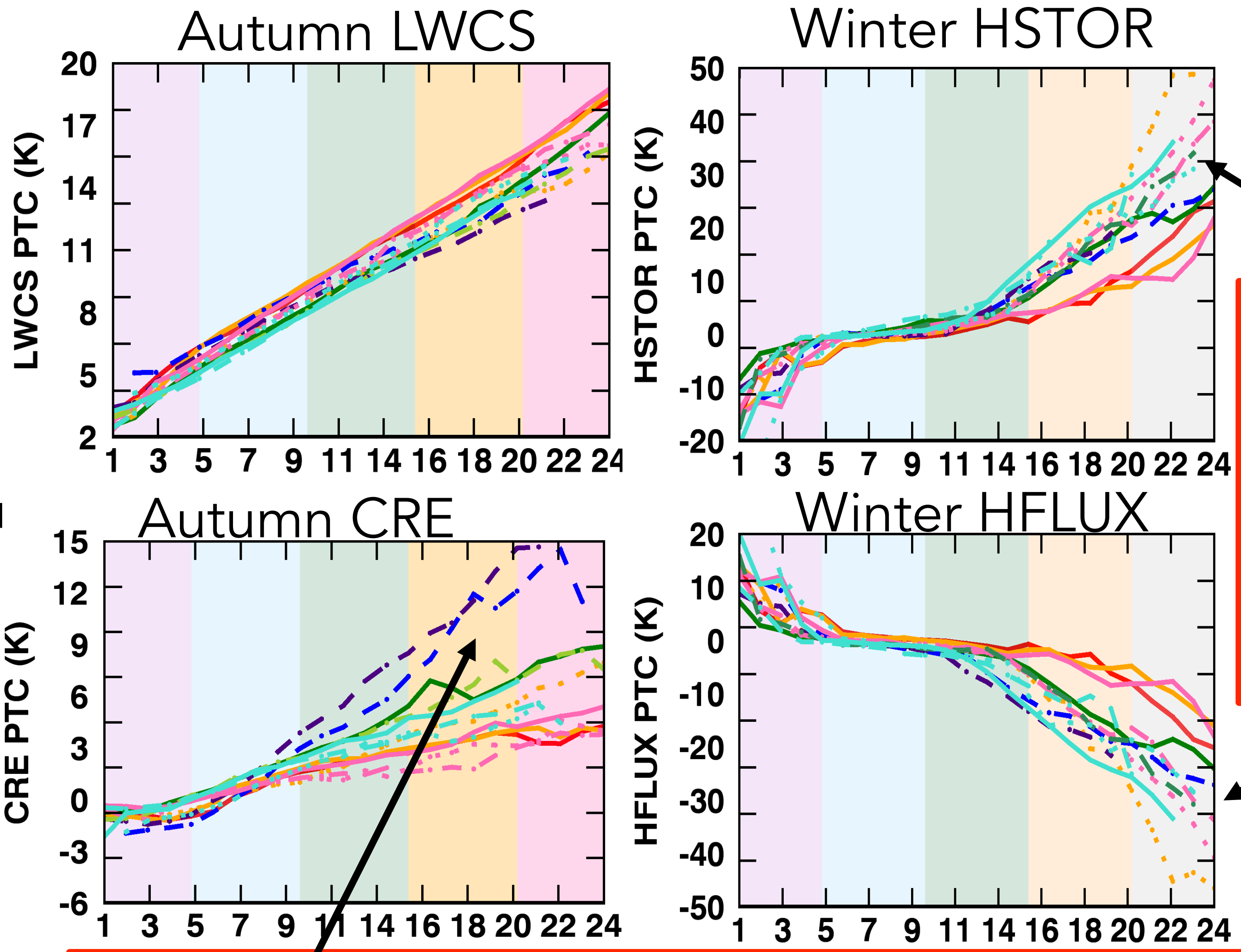


Regions that warm most have the largest feedback contributions…most of the time



SAF exhibits a U-shape meaning that both regions of small and large warming exhibit a strong feedback.

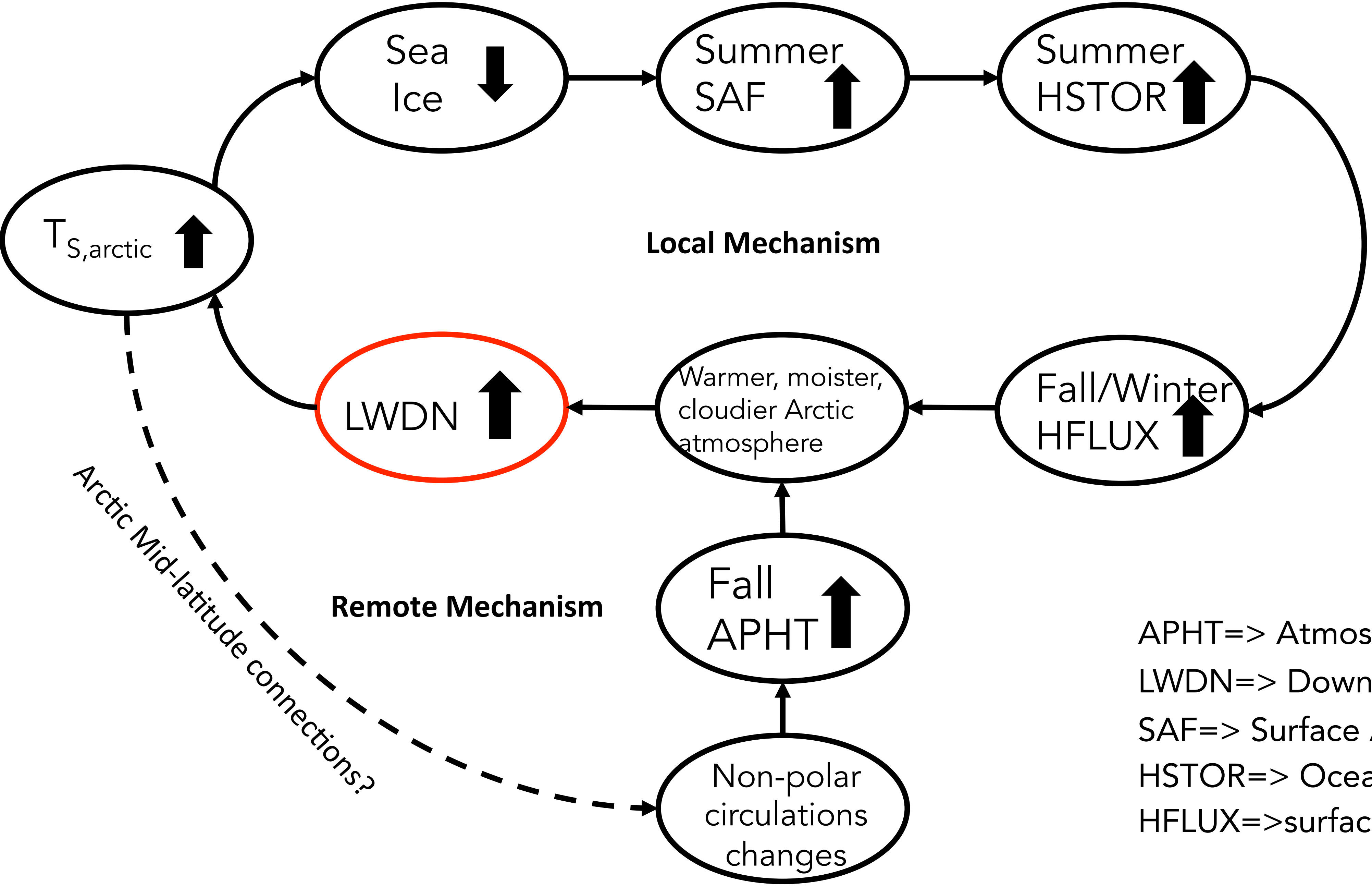
Boeke and Taylor (in revision)



HSTOR and HFLUX show equal and opposite values.

Two models dominate the spread in cloud feedback

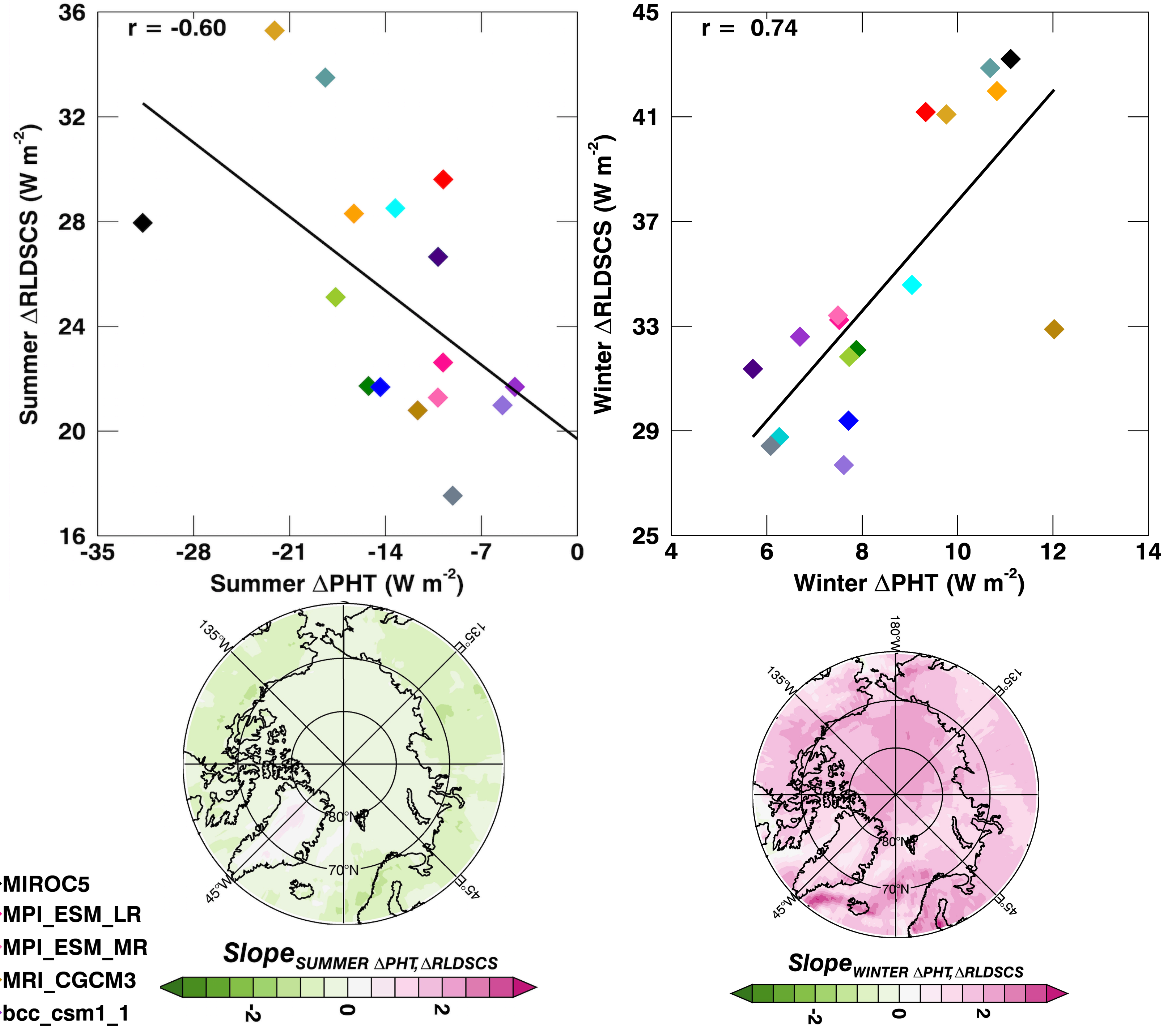
A complete picture of Arctic Amplification?

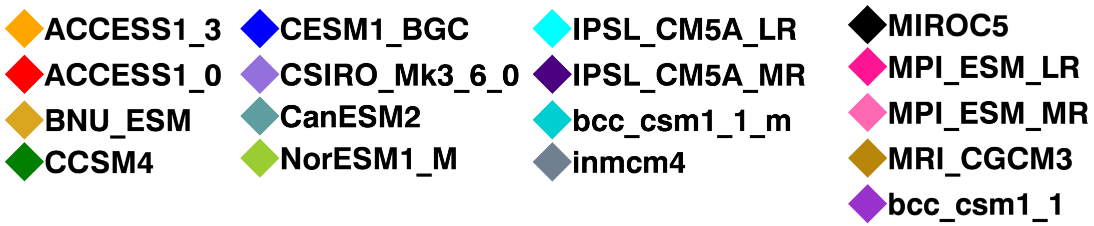


LWDN is the dominant term contributed to Arctic Amplification.

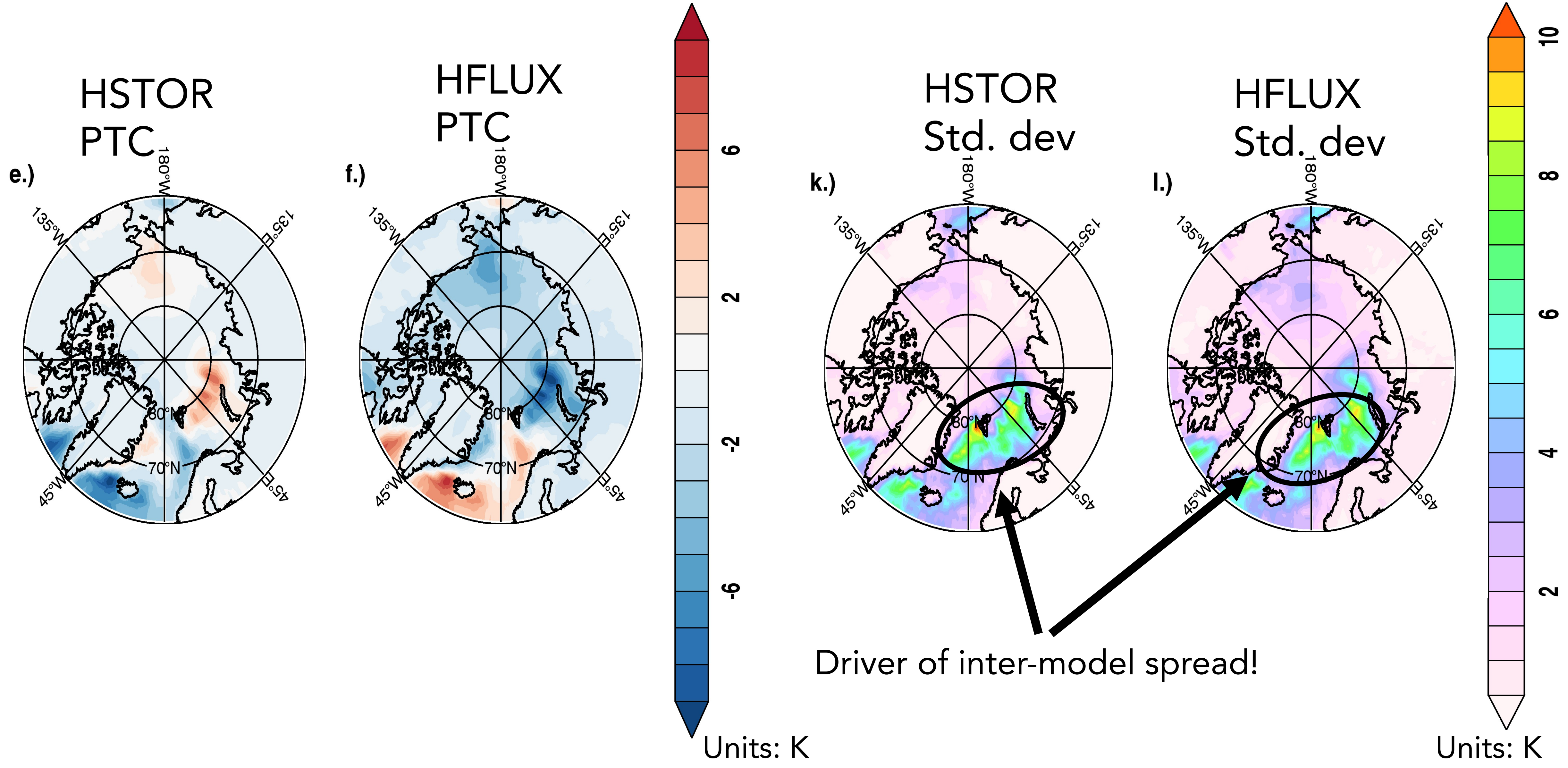
APHT=> Atmos. Poleward heat transport
LWDN=> Downward LW radiation
SAF=> Surface Albedo Feedback
HSTOR=> Ocean heat storage/transport
HFLUX=>surface turbulent fluxes

Atmospheric poleward heat transport induces a spatially uniform warming.

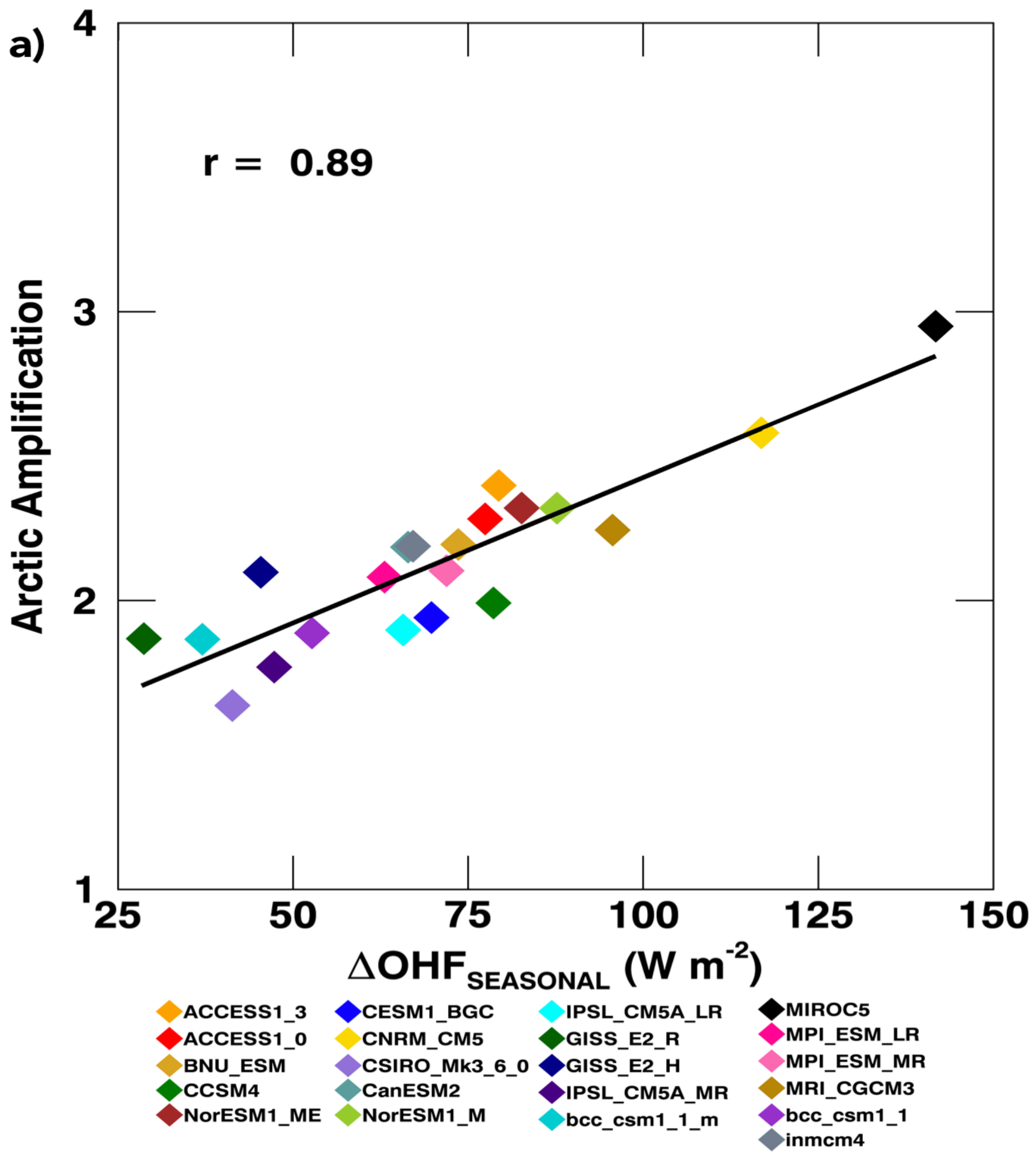




Local mechanism sets the spatial structure of Arctic amplification.



A larger annual cycle ocean heat storage amplitude increase=>larger projected warming

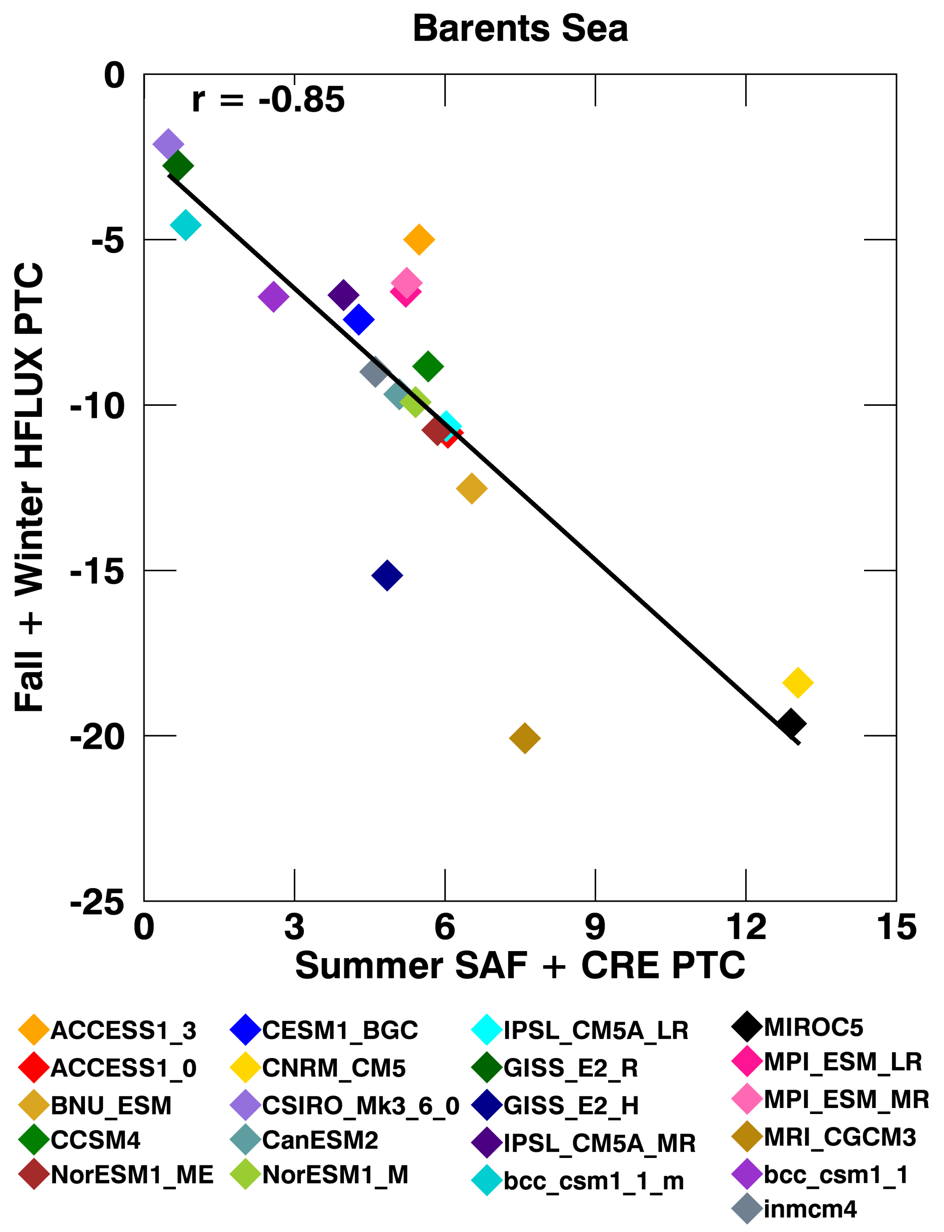


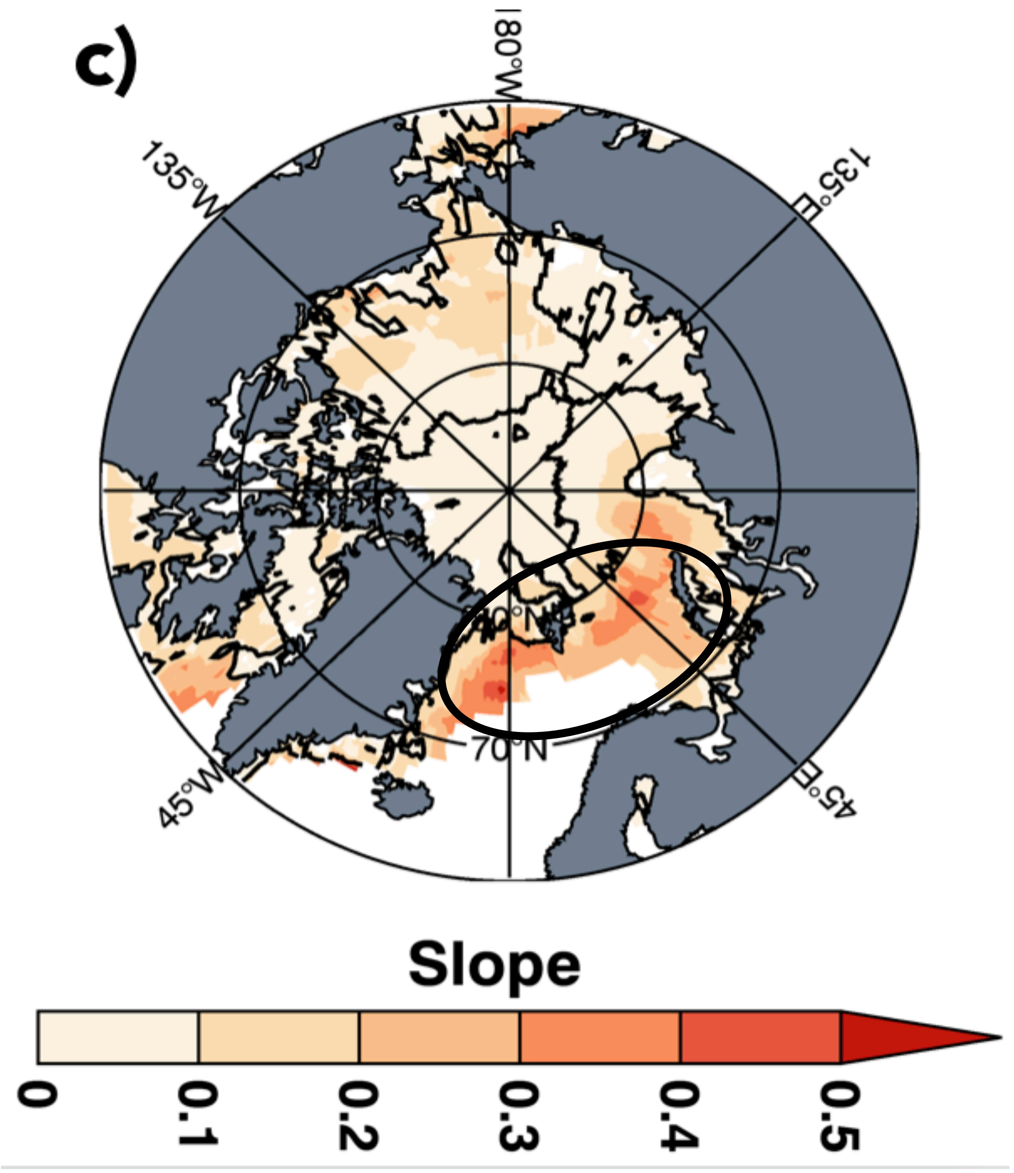
A strong positive correlation is found between the changes in the seasonal amplitude of ocean heat storage and projected Arctic Amplification.

Thus, processes controlling the seasonality of ocean heat storage (upper ocean mixing, absorbed solar radiation, surface turbulent fluxes) may hold the key to unraveling inter-model differences in Arctic Amplification.

Summer=>ability to store energy (mixed layer depth, ASR)
Fall/winter=>ability to release energy (surface turbulent fluxes)

Models increase both SAF and fall/winter HFLUX

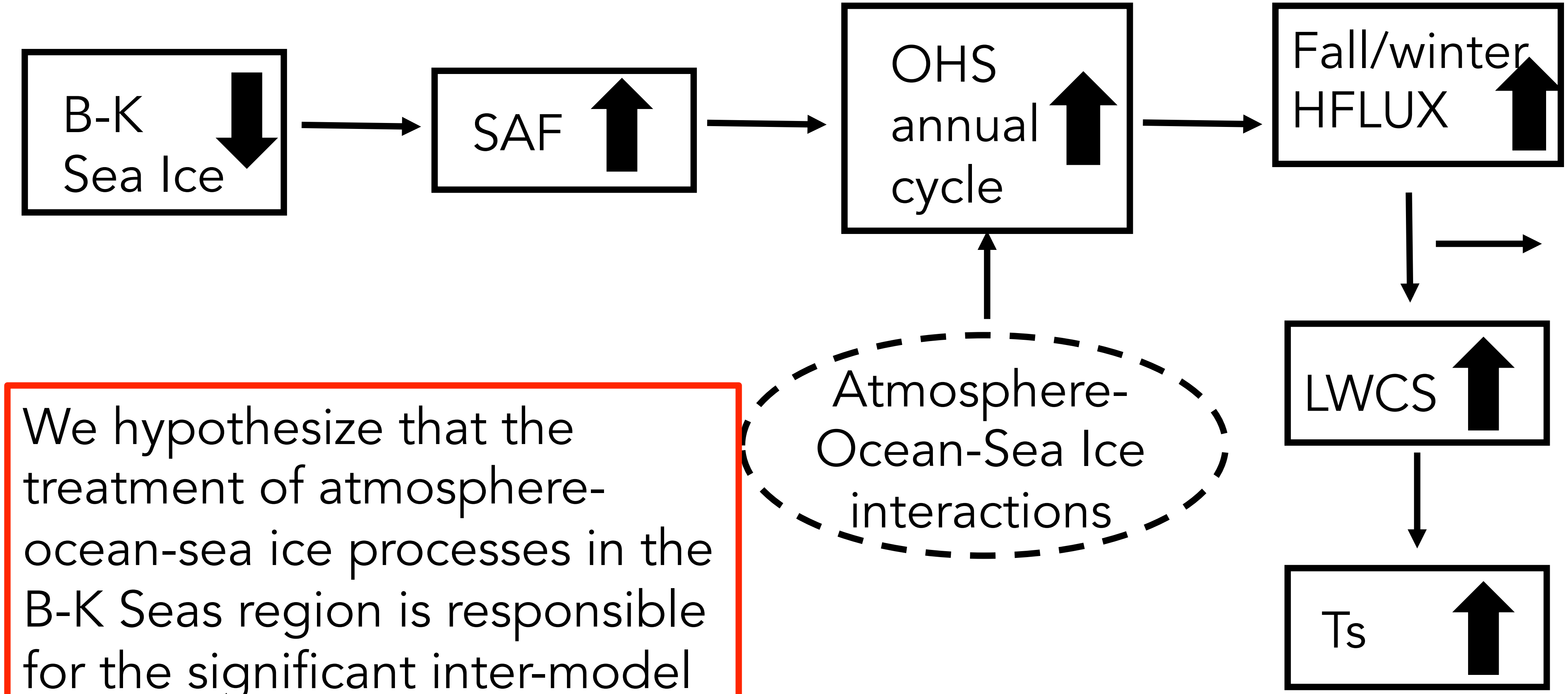




Surface turbulent flux changes in the Barents-Kara Seas region are show a statistically significant relationship with the model simulated SAF.

A picture of AA and the inter-model spread

LWCS sets the Arctic-wide magnitude of warming, and explains way all models produce AA. Both models and spatial regions with the largest LWCS increases, warm more.



We hypothesize that the treatment of atmosphere-ocean-sea ice processes in the B-K Seas region is responsible for the significant inter-model differences in AA.

We hypothesize that the connection between the B-K Seas region and the rest of the Arctic (via LWCS) is controlled by the atmospheric circulation response.

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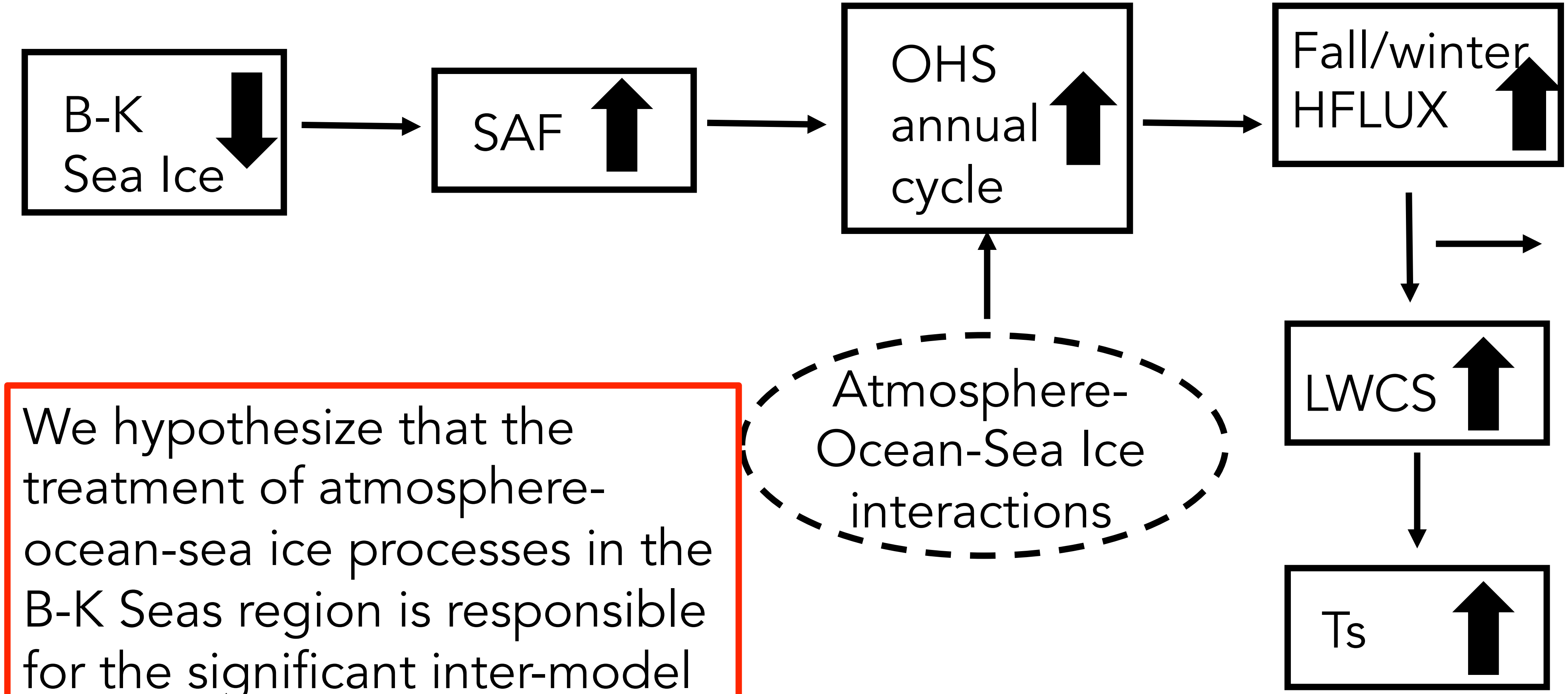

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Takeaway messages:

(1) Physical process of Arctic Amplification. Barents-Kara Sea region as a pacemaker of warming.

(2) Do clouds matter to Arctic Amplification and sea ice loss? Yes. However, the most important aspect may not be the direct impact, but rather indirect impacts by modulating other responses (e.g., the circulation response)

(3) What is the way forward? System approaches and multi-disciplinary perspectives.

Increased B-K Sea region surface turbulent fluxes have an Arctic-wide impact

Surface turbulent flux changes in the Barents-Kara Seas region show an Arctic-wide impact on LWCS, magnitude of which is strongest locally.