Do changes in poleward atmospheric heat transport force or respond to polar amplification?

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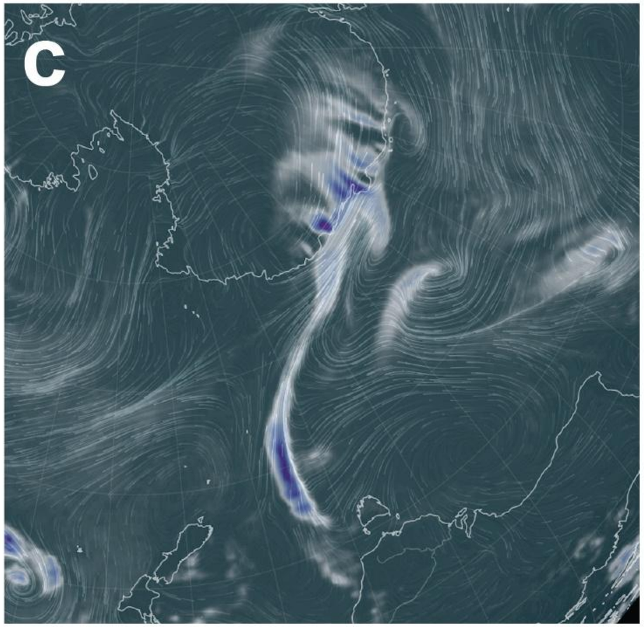
Edward Blanchard-Wrigglesworth IV– UW atmospheric science
Tyler Cox – Retired scientist
Molly Wieringa -- UW atmospheric science

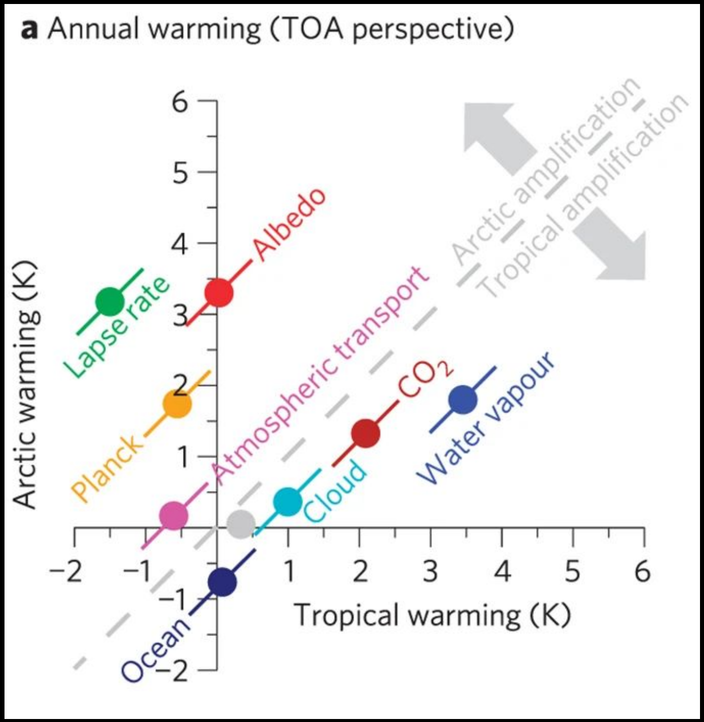
Antarctic Atmospheric River Event
March 16, 2022



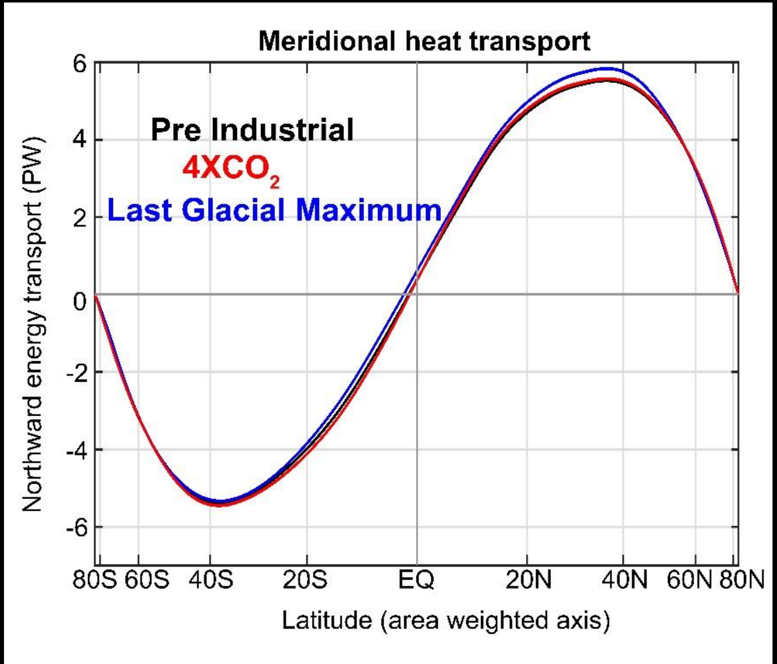
Water vapor image during the largest ever recorded heatwave

Photo credit: University of Maine, NOAA

Atmospheric heat transport into the polar regions barely changes under global warming



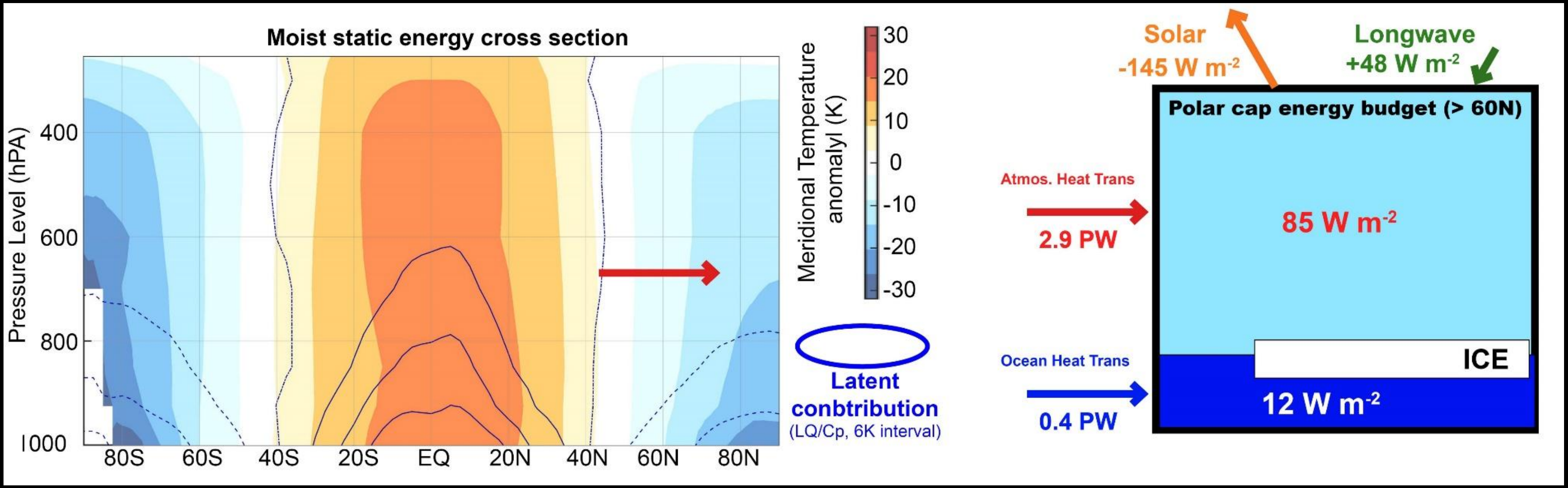
Atmospheric heat transport changes make no contribution to Arctic warming under global warming (Pithan and Mauritsen, 2014)



More generally, (coupled) poleward energy transport is nearly climate state invariant from the Last Glacial Maximum to CO_2 quadrupling

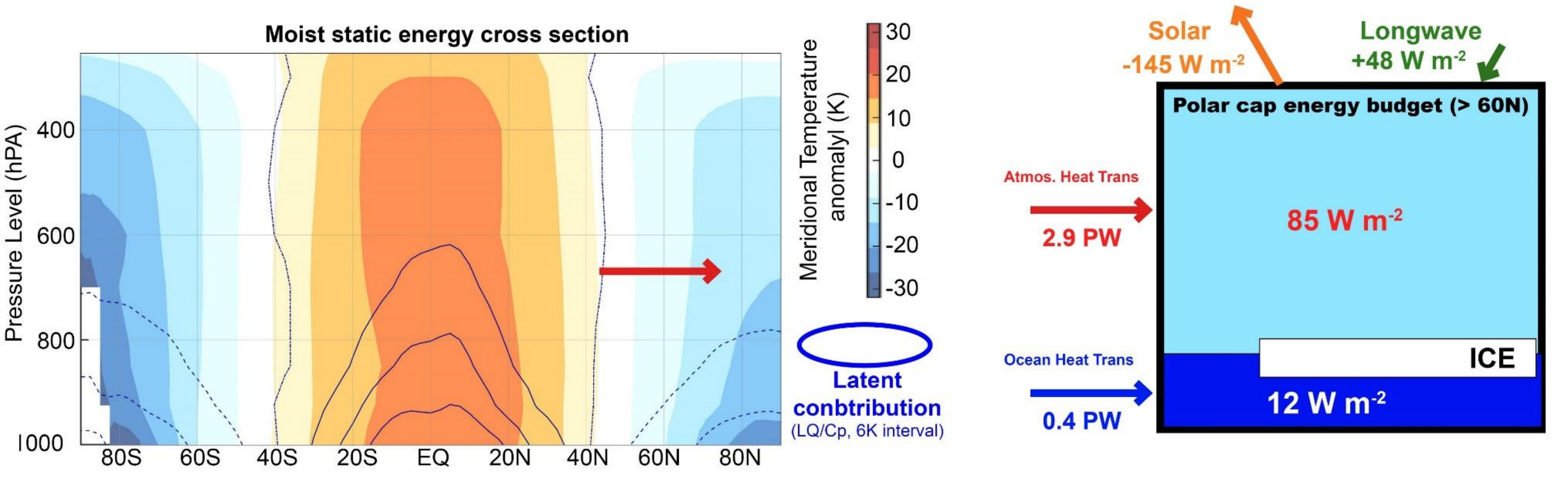
Arctic response to increased poleward heat transport

Mean State

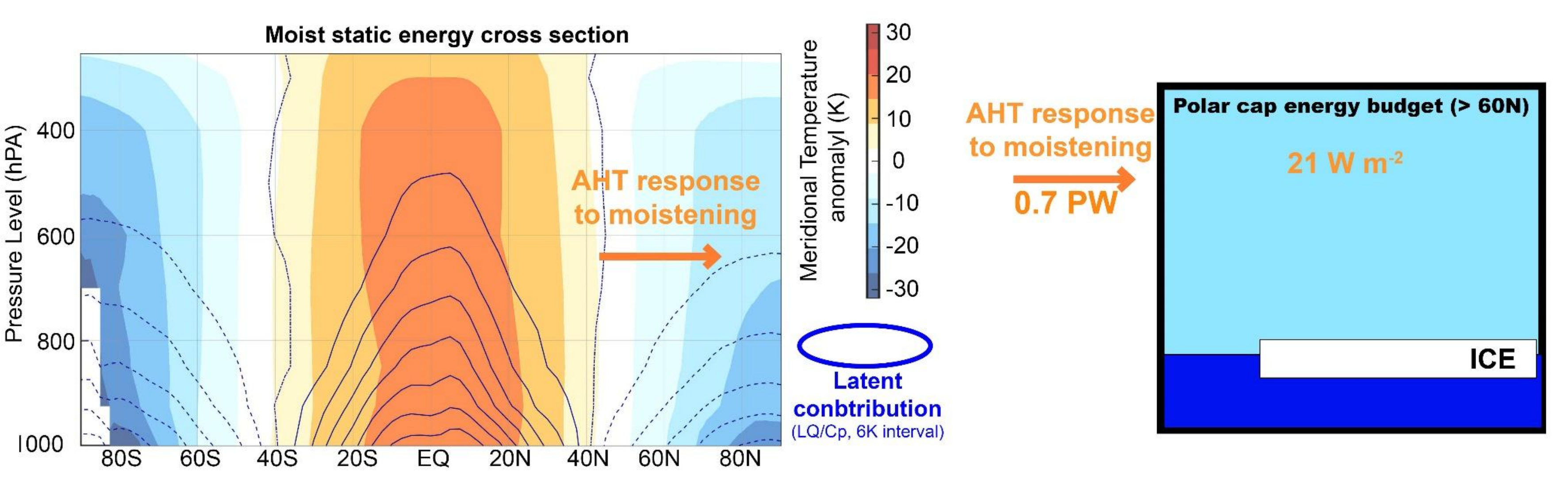


Arctic response to increased poleward heat transport

Mean State

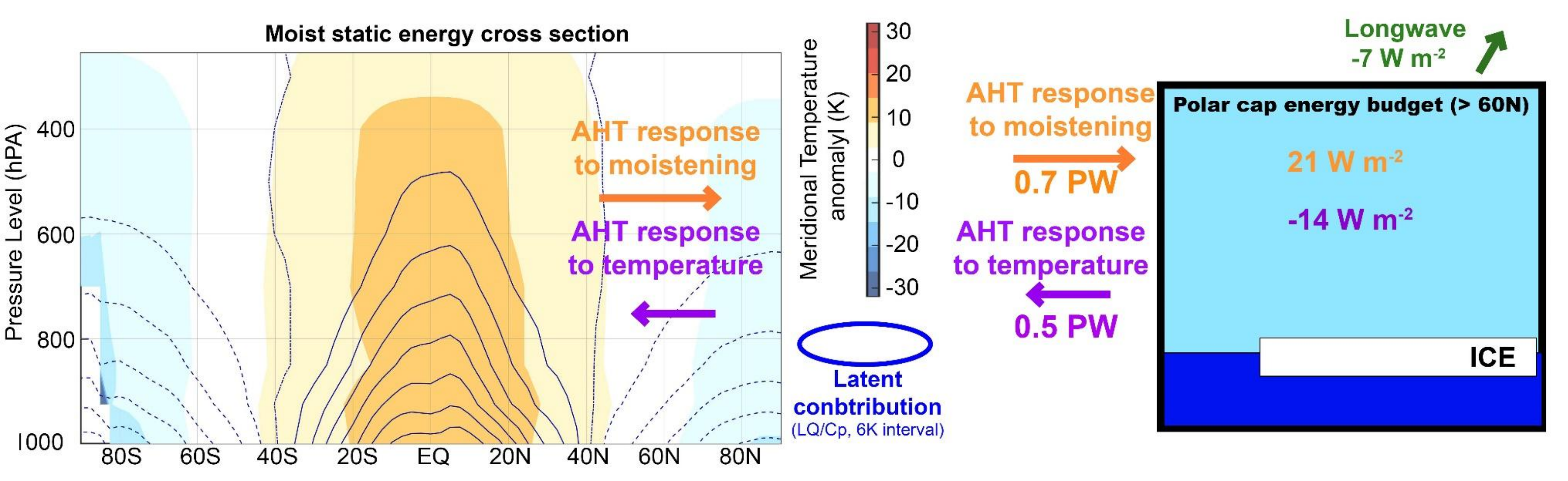


Spatially uniform global warming (+10K)



Arctic response to increased poleward heat transport

Adjusted state



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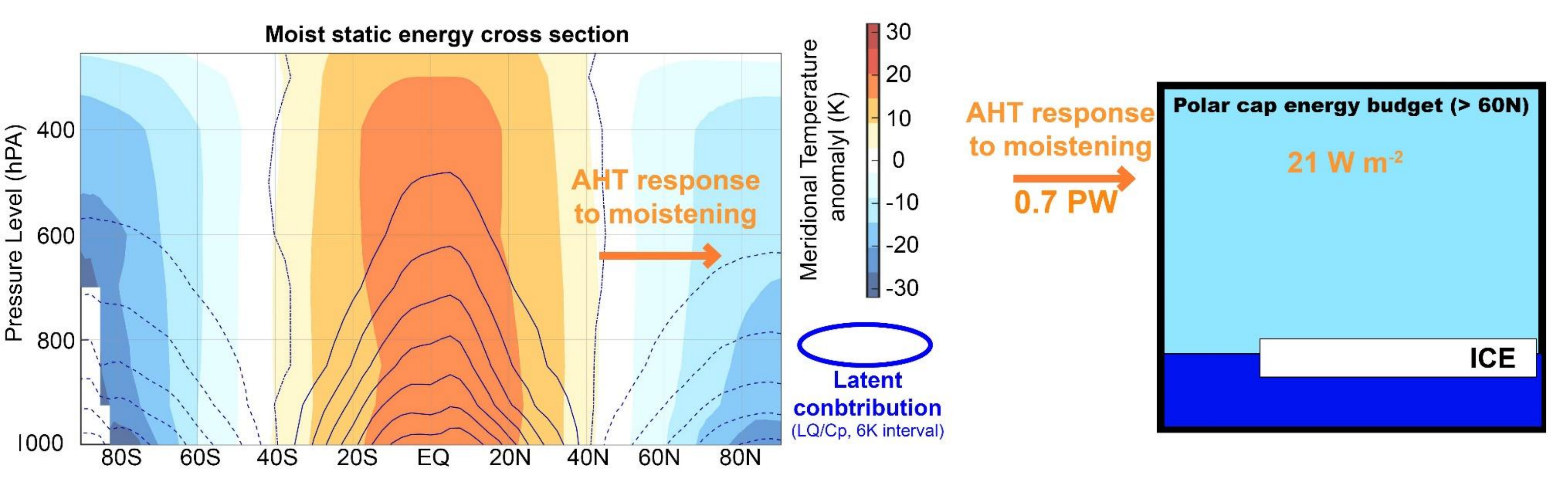

Arctic response to increased poleward heat transport

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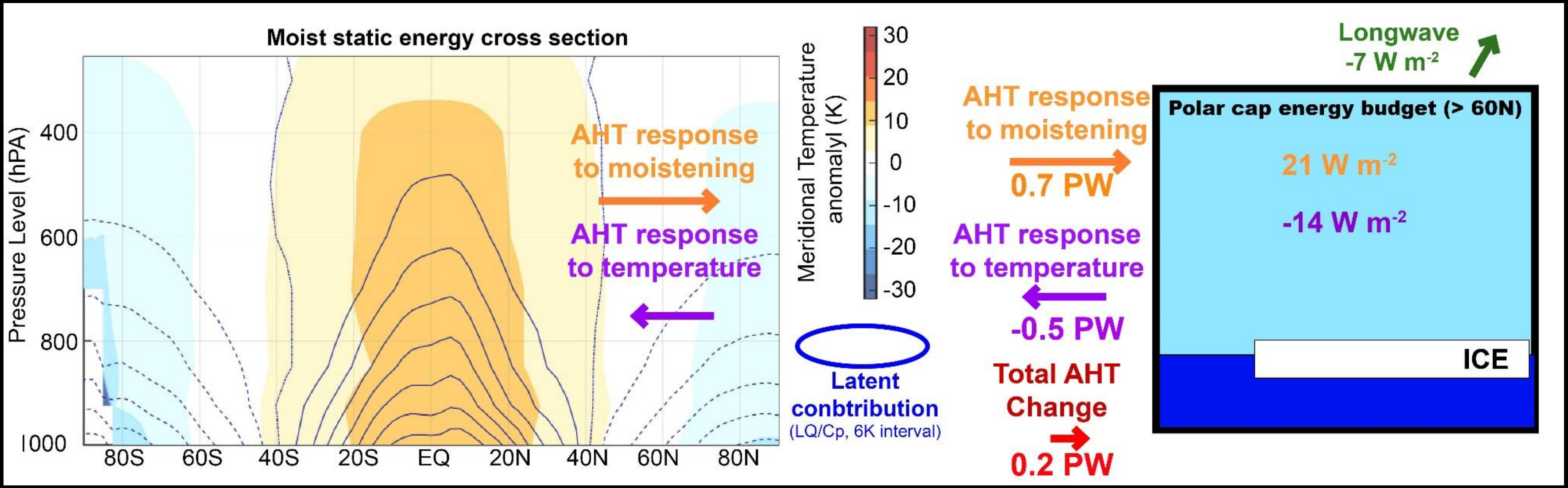

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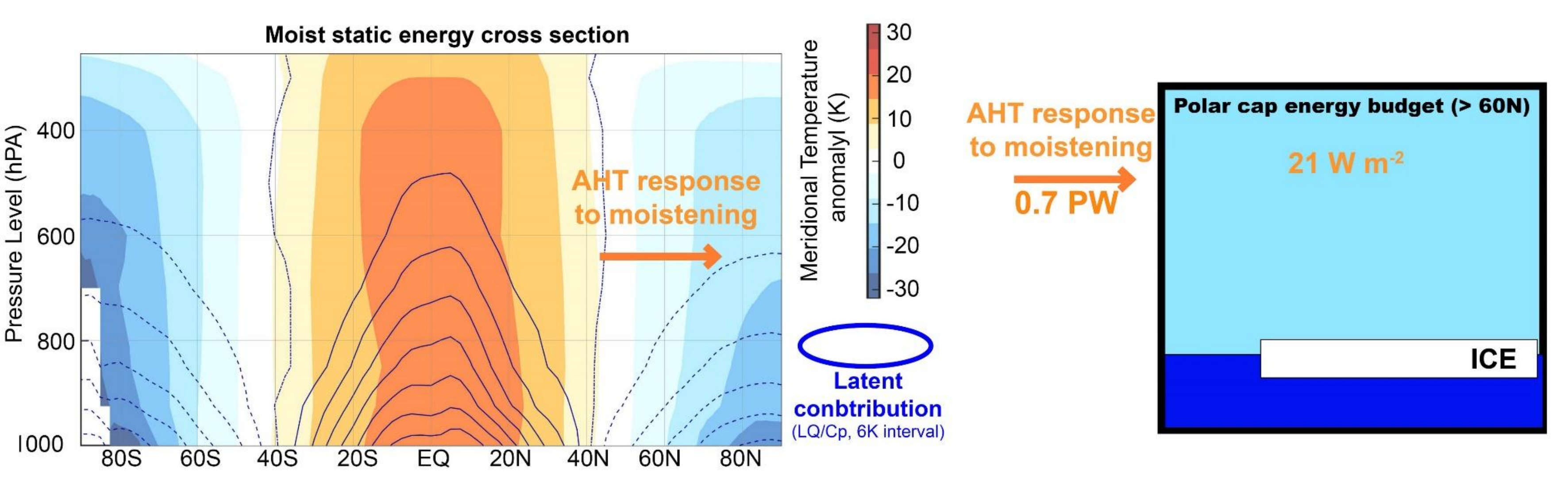

Arctic response to increased poleward heat transport

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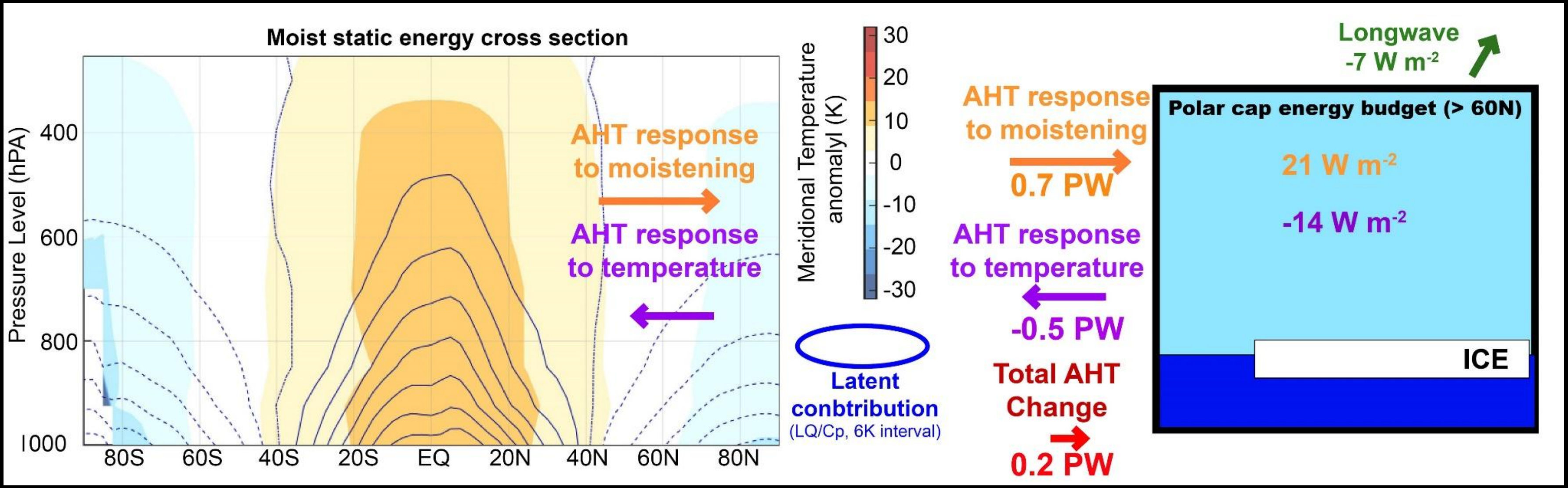
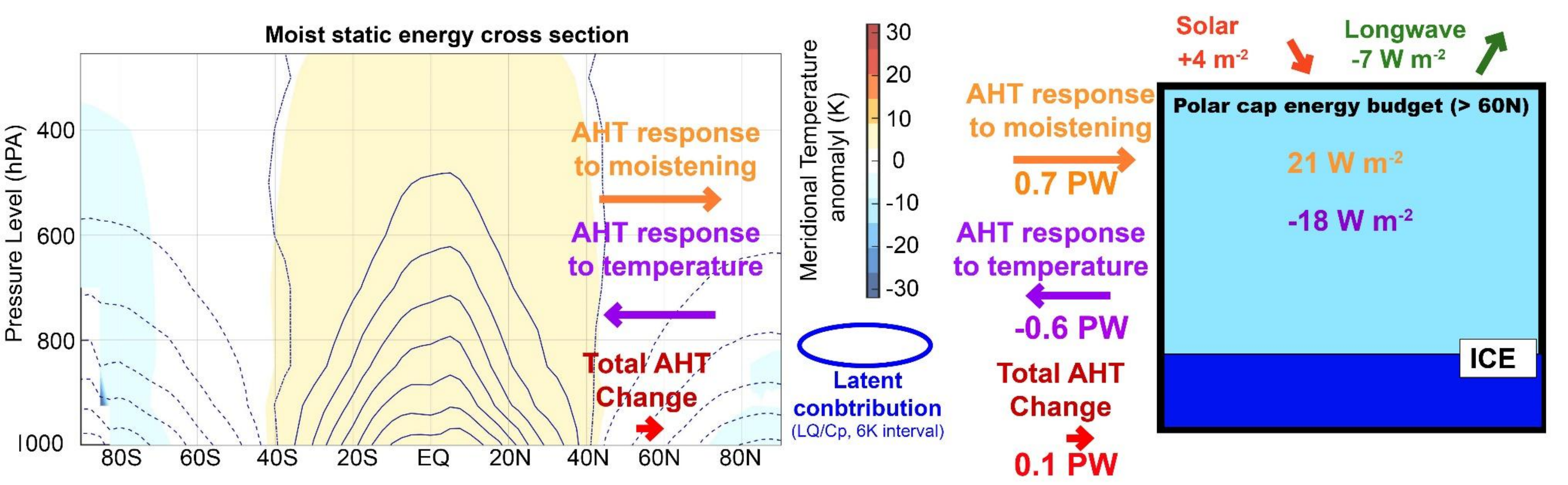
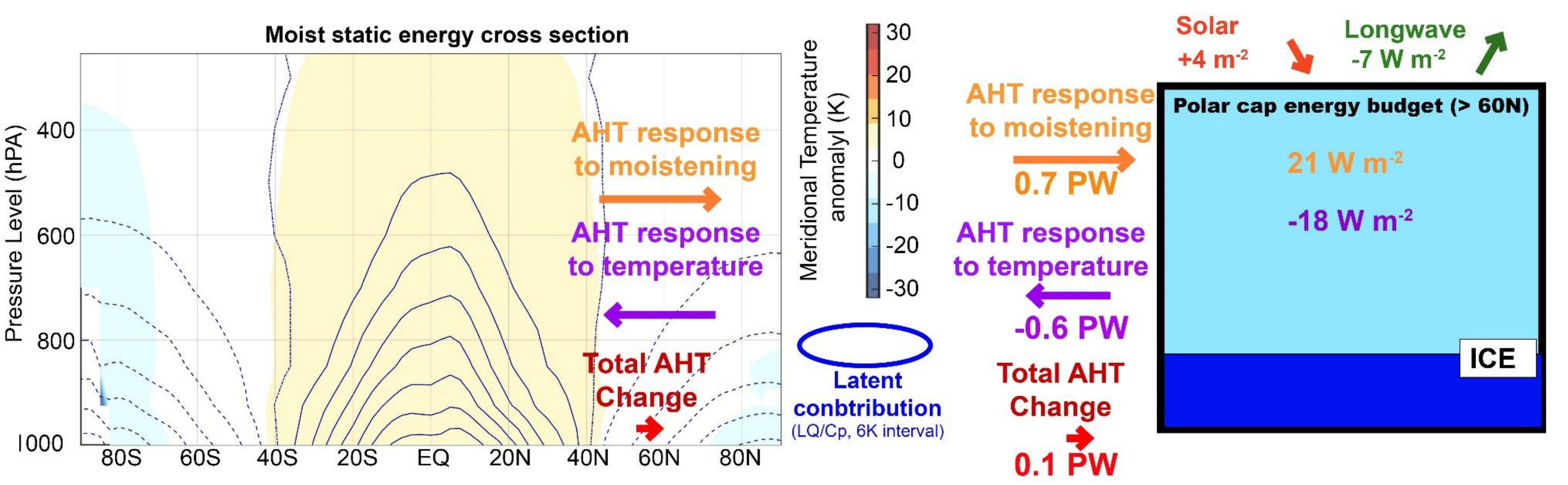


Adjusted state with ice albedo feedback



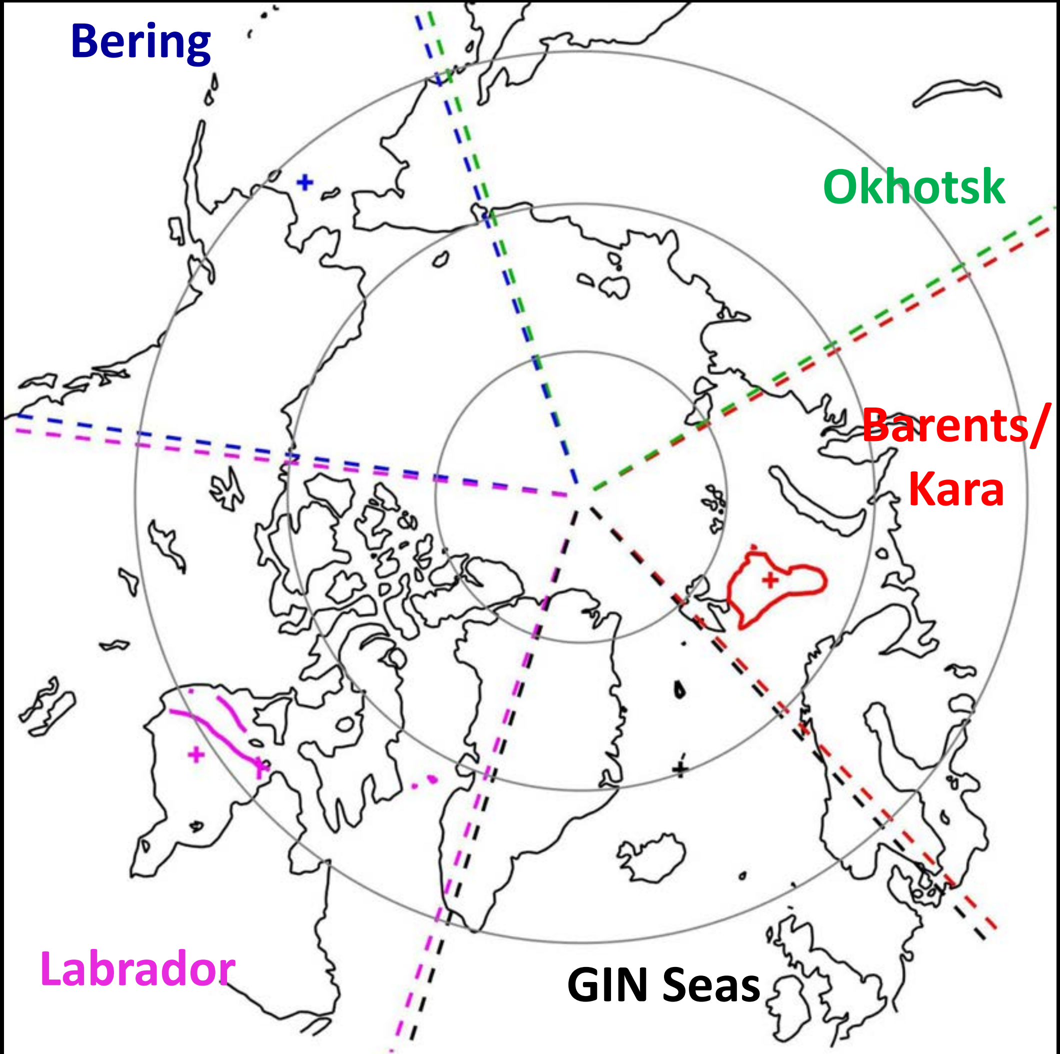


Key point: The expected Arctic energetic adjustment to increased poleward heat transport is polar amplified warming and **a reduction in poleward heat transport**

 Because dynamic feedbacks are stronger than radiative feedbacks

Temporal evolution of AHT associated with (2σ) sea ice loss events in CESM1 – wintertime

10 days before max anomaly



Sea Ice Concentration Anomaly (interval 10%)

Composites are made

- Independently for each region but presented together for compactness
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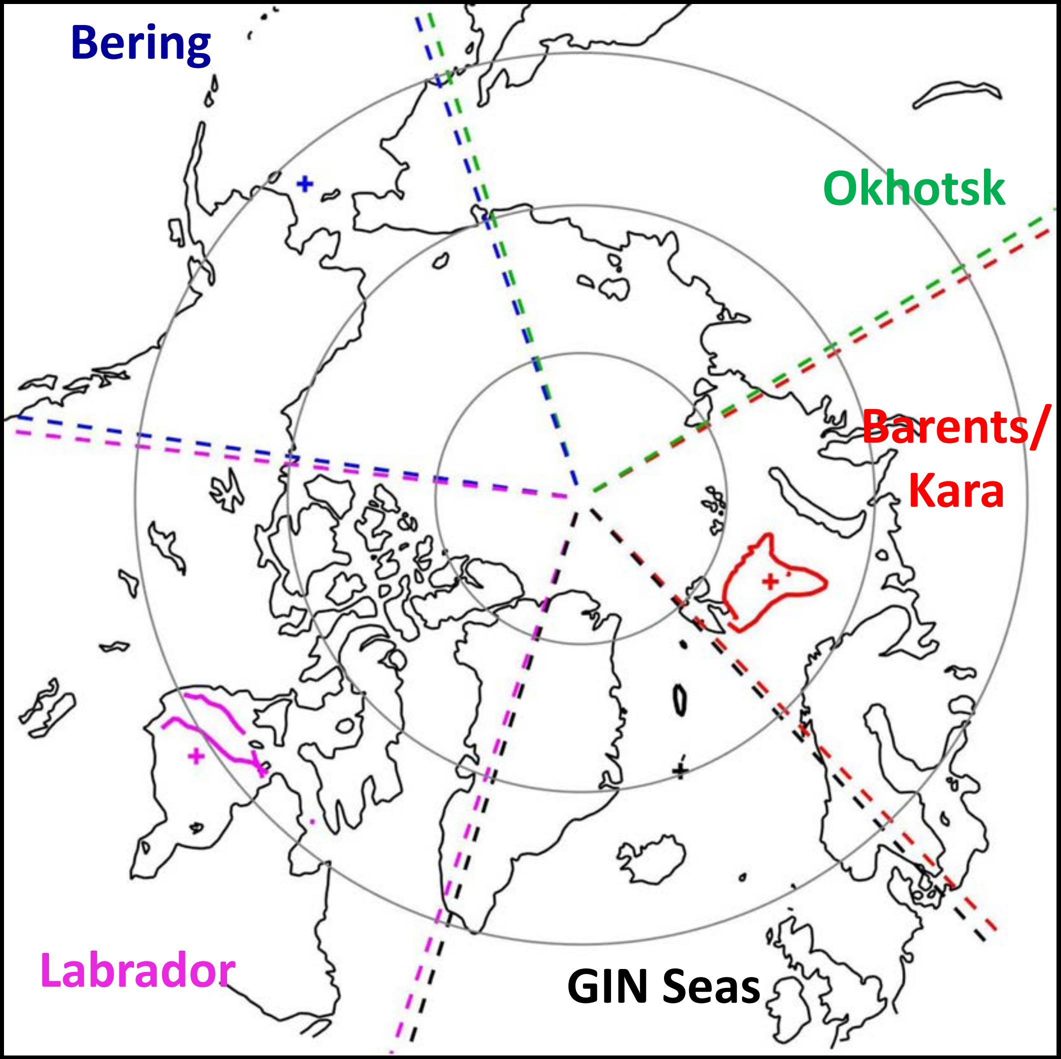
Temporal evolution of AHT associated with (2σ) sea ice loss events in CESM1 – wintertime

8 days before max anomaly



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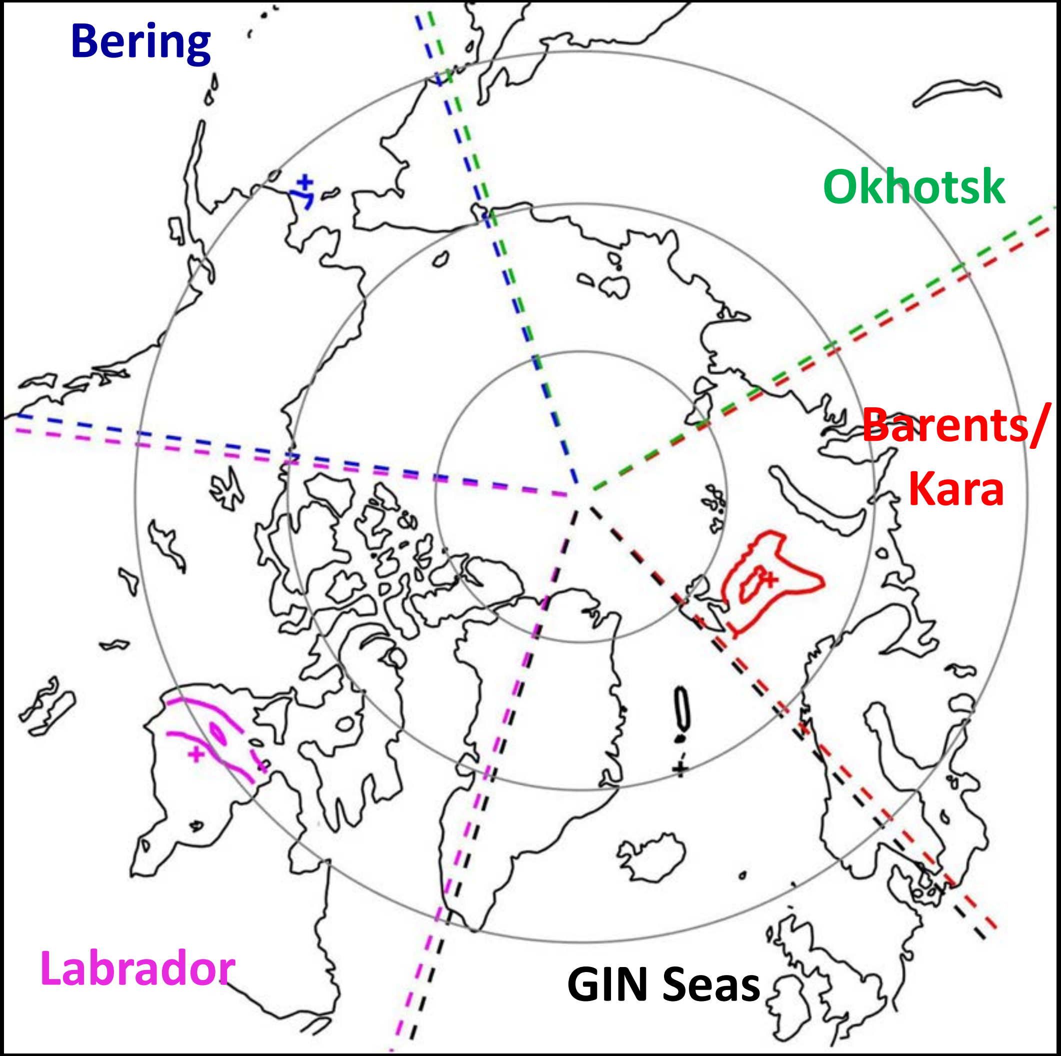
6 days before max anomaly



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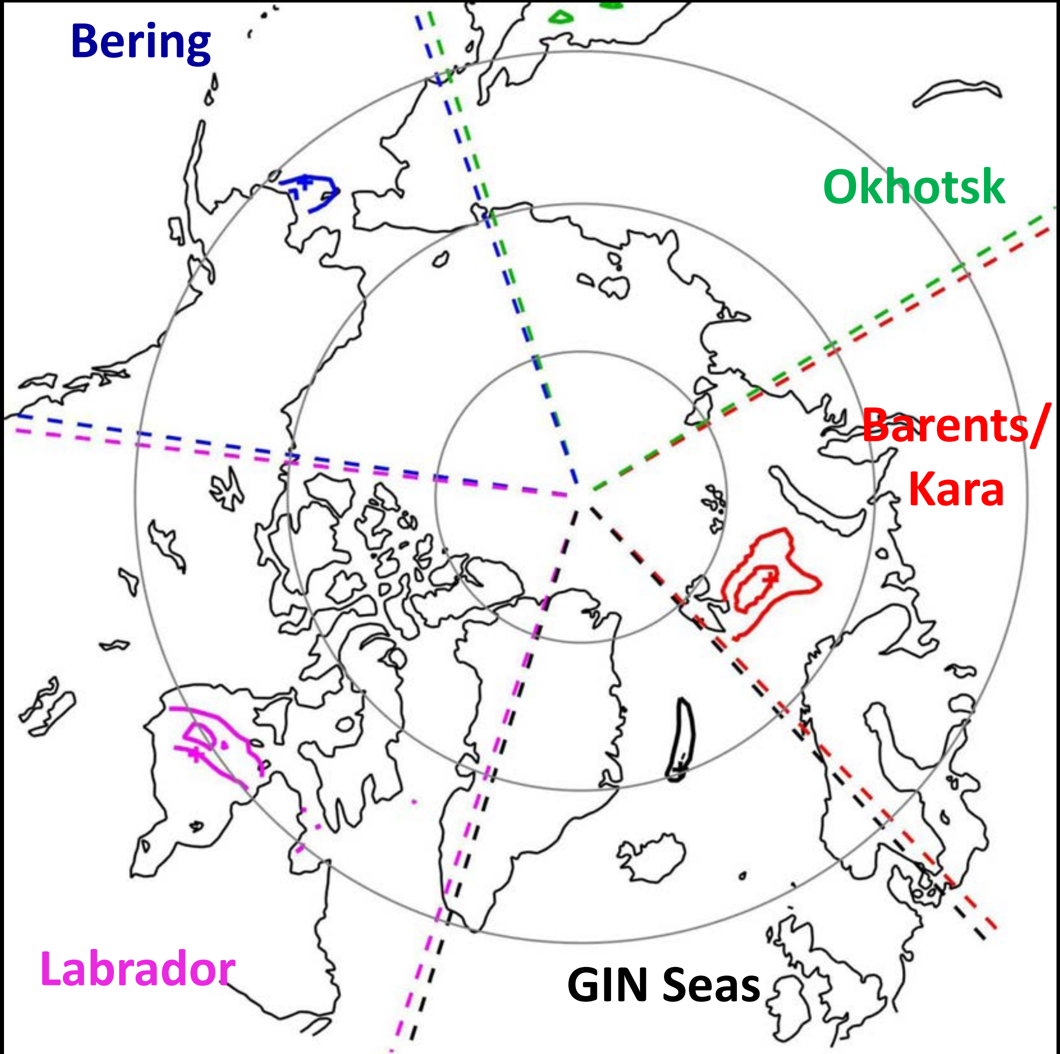
4 days before max anomaly



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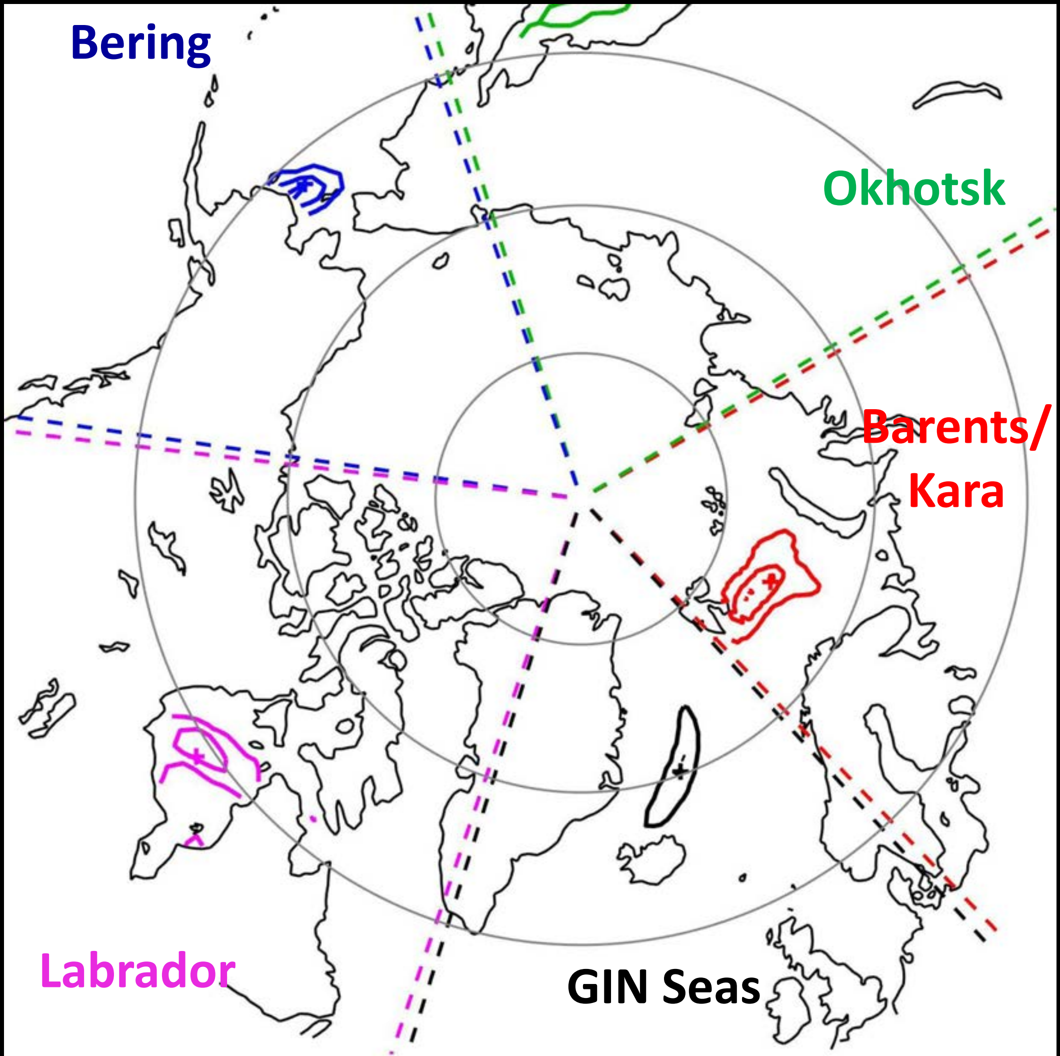
2 days before max anomaly



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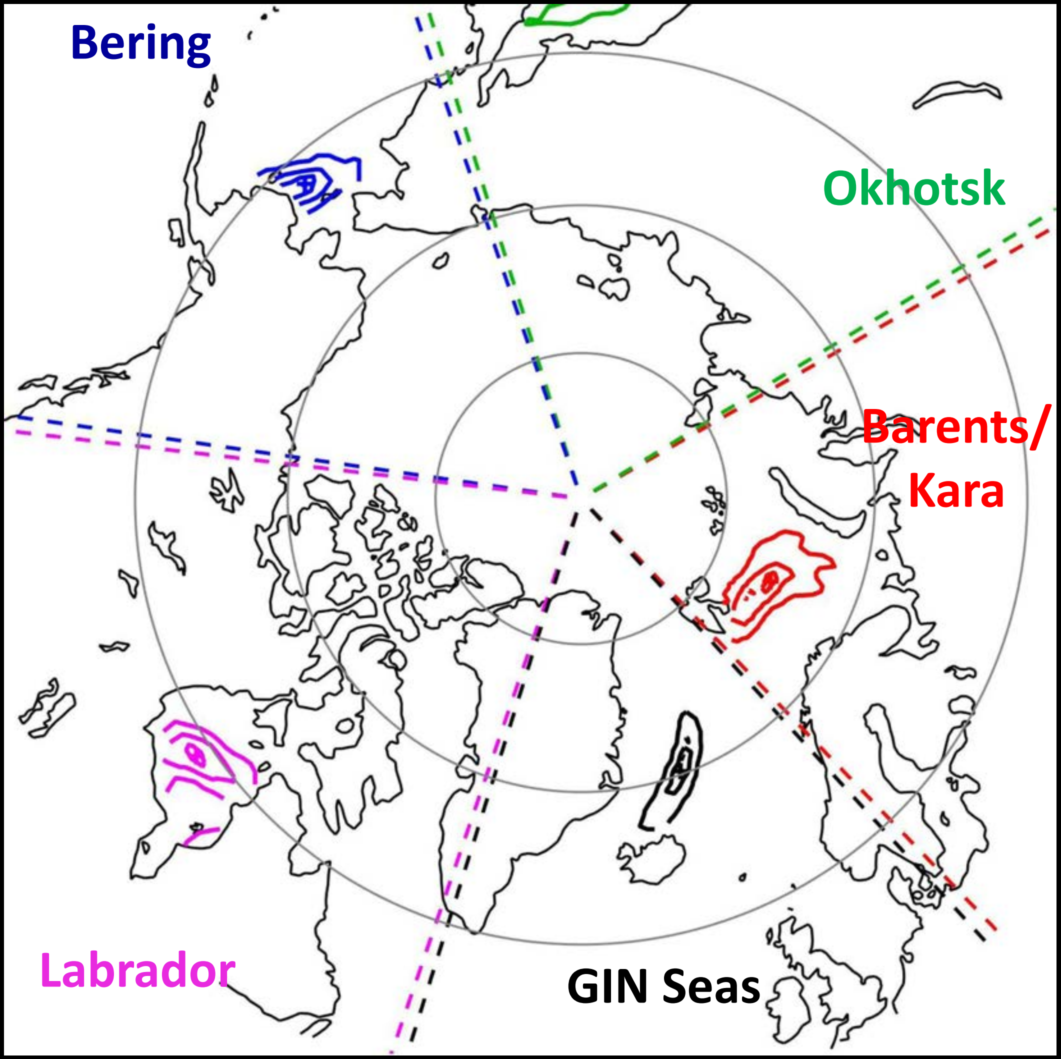
at max anomaly



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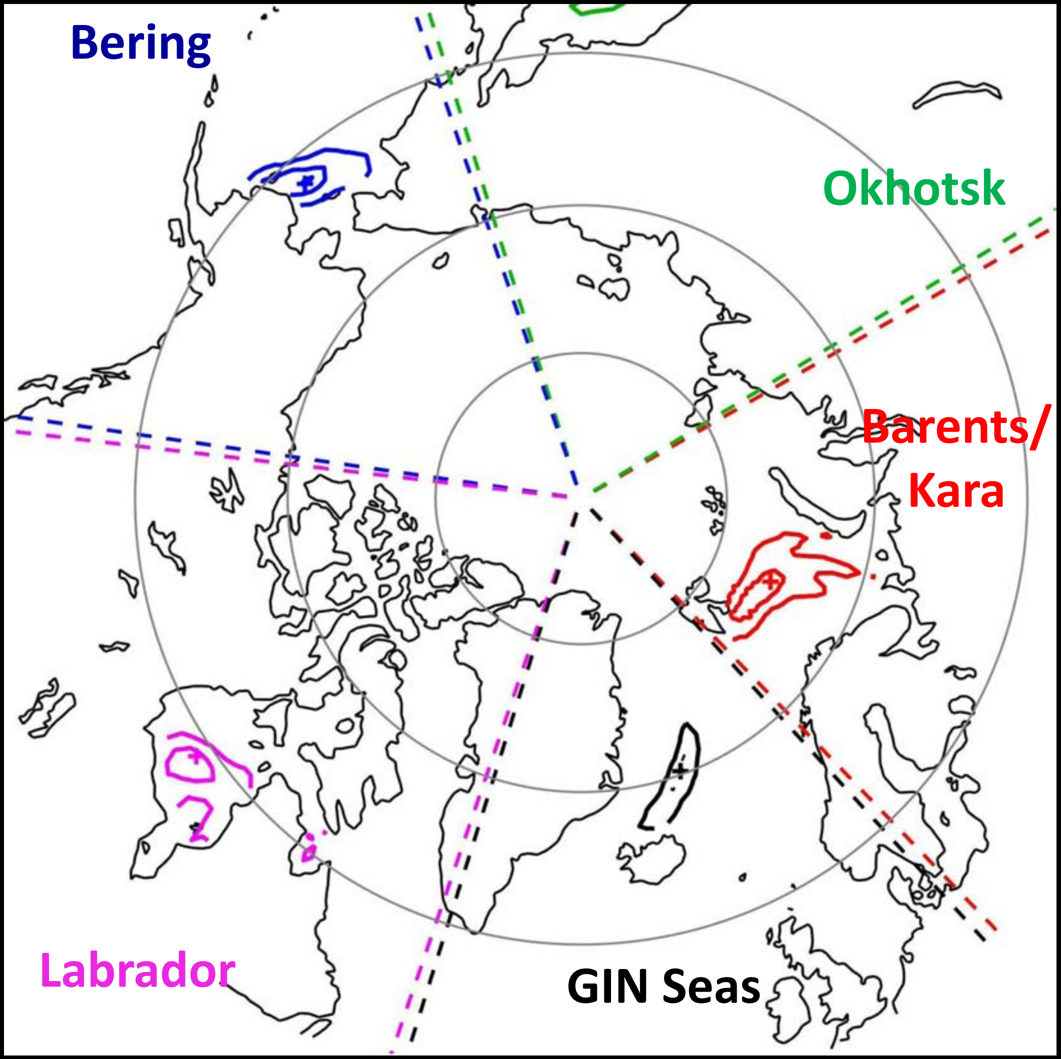
Temporal evolution of AHT associated with (2σ) sea ice loss events in CESM1 – wintertime

2 days after max anomaly



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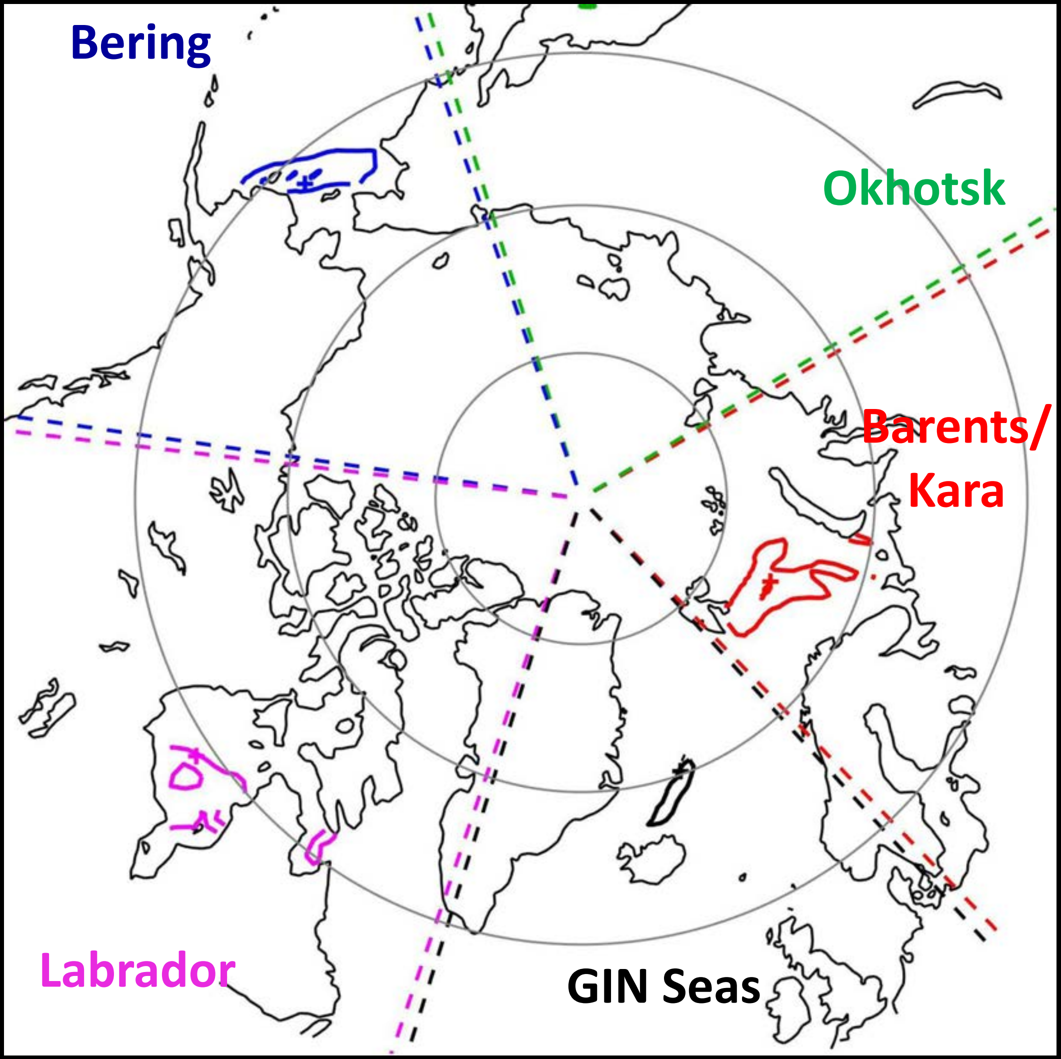

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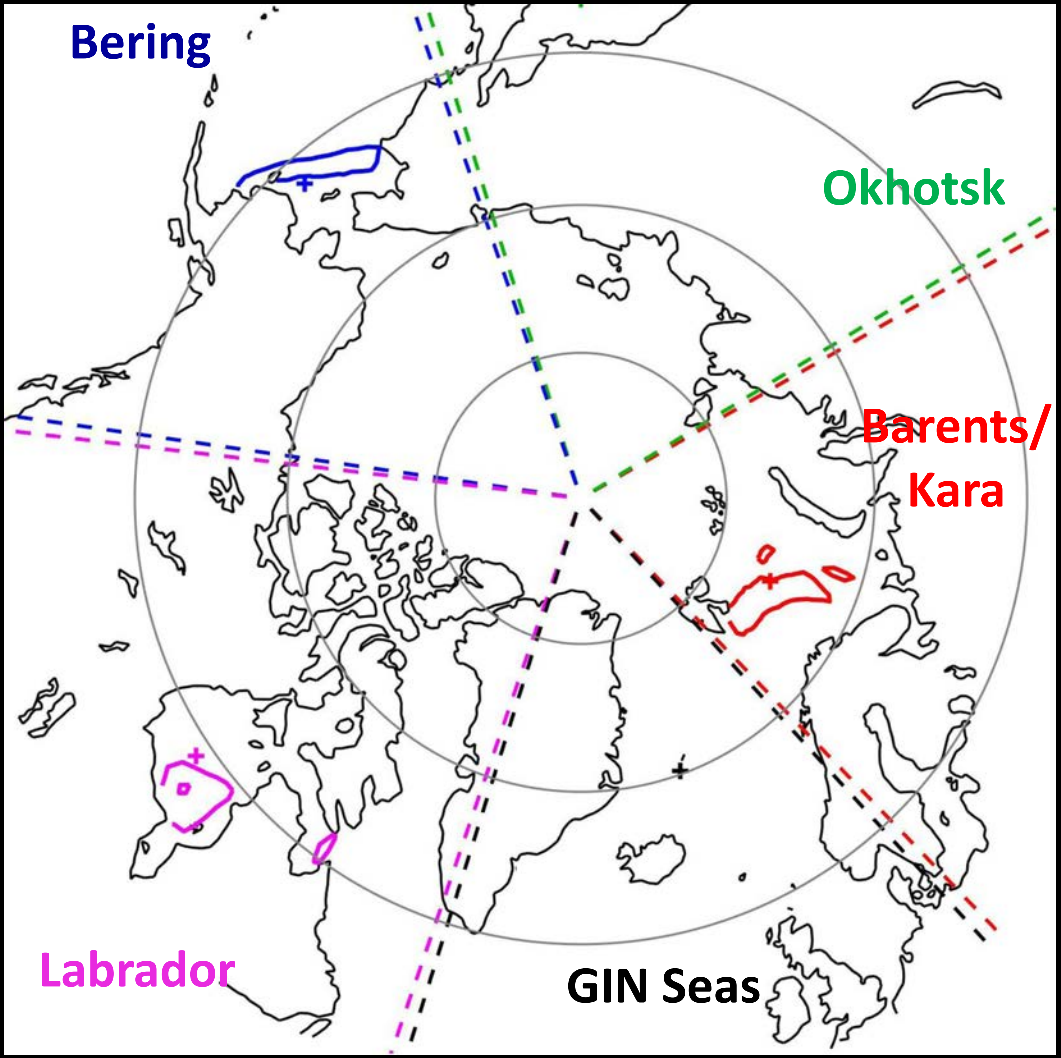

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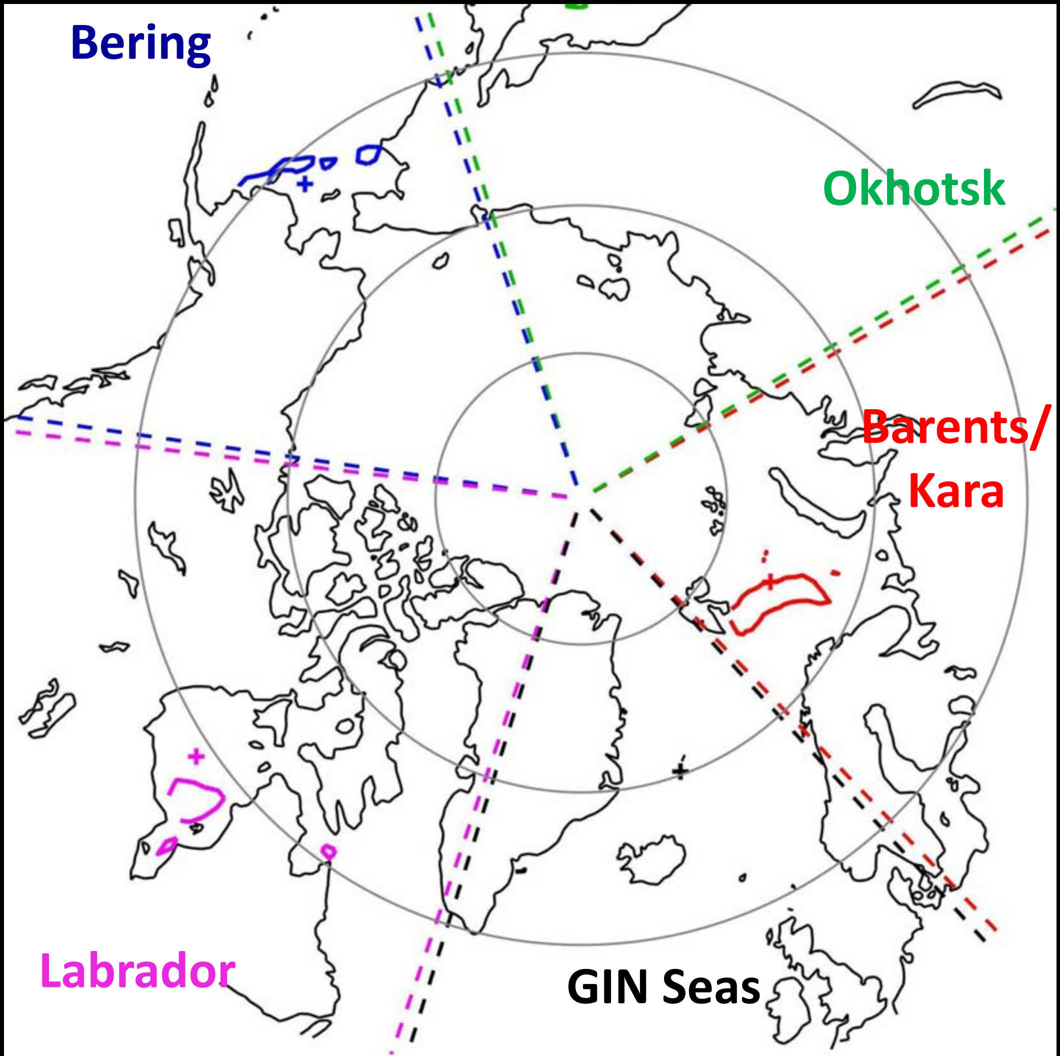
8 days after max anomaly



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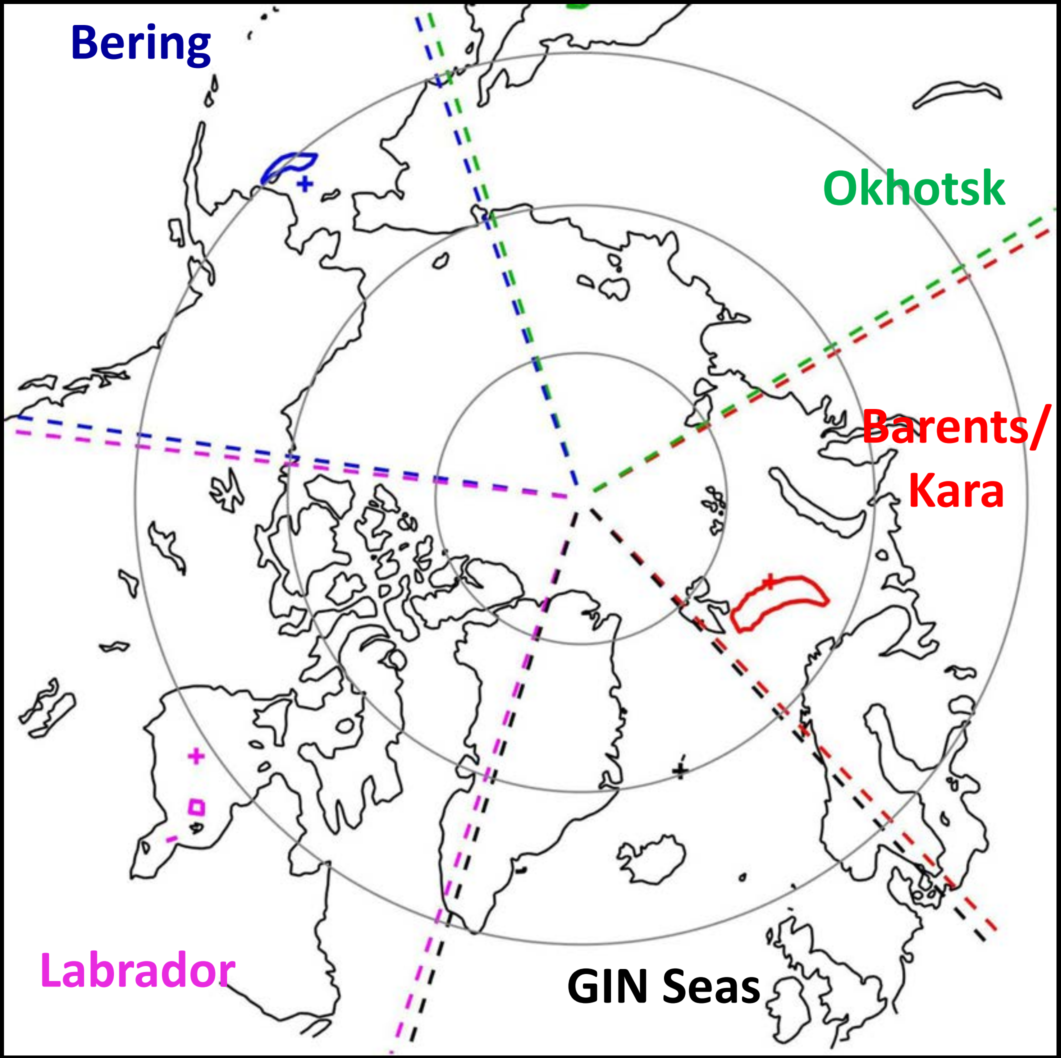
10 days after max anomaly



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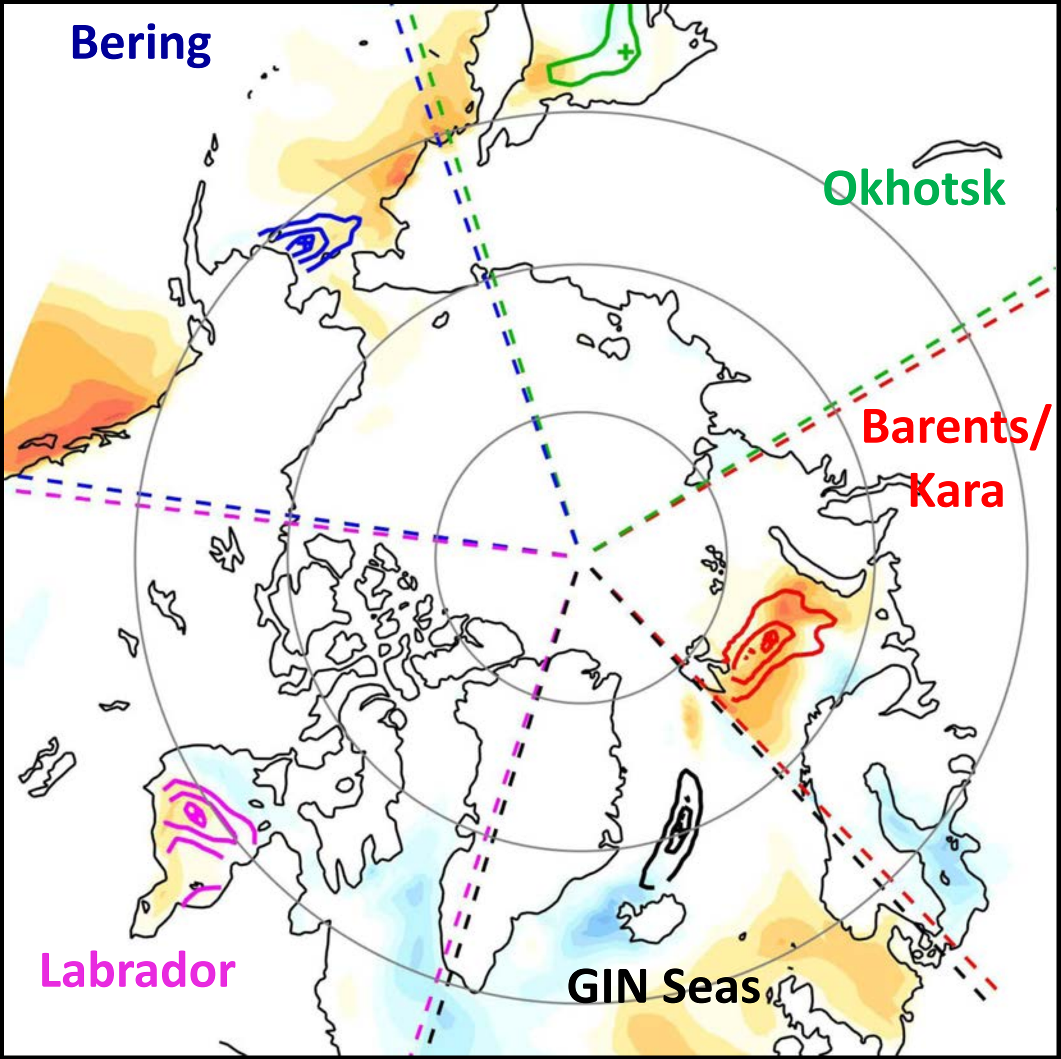
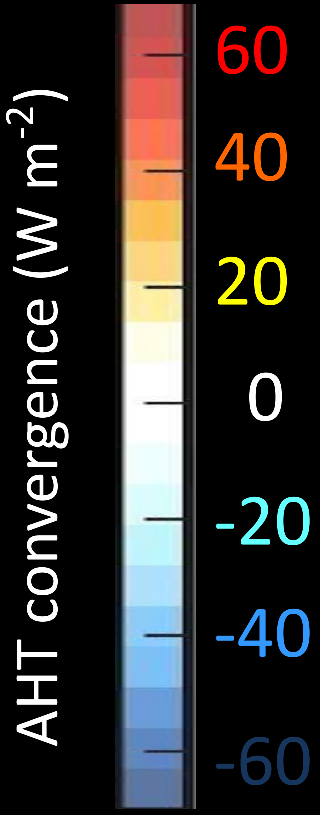
AHT 10 days before

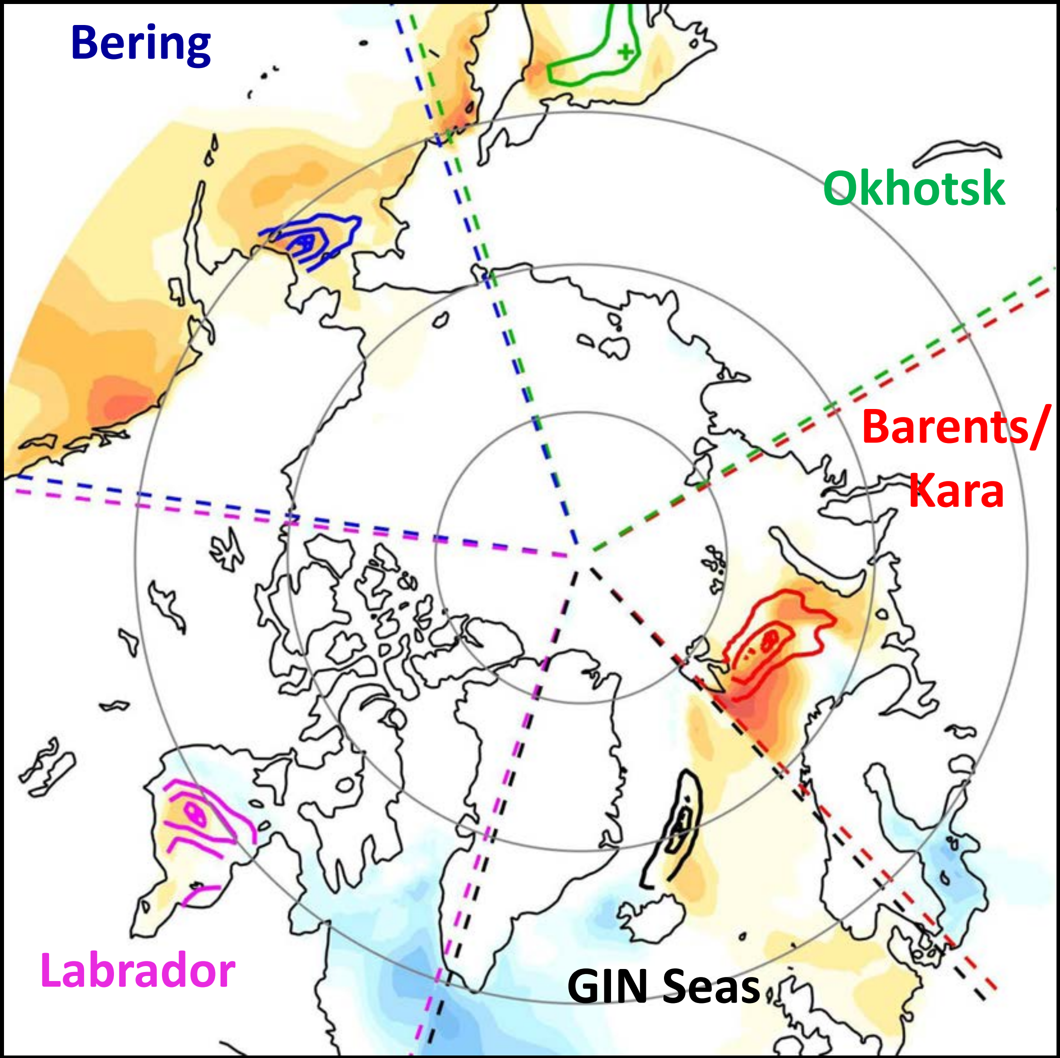


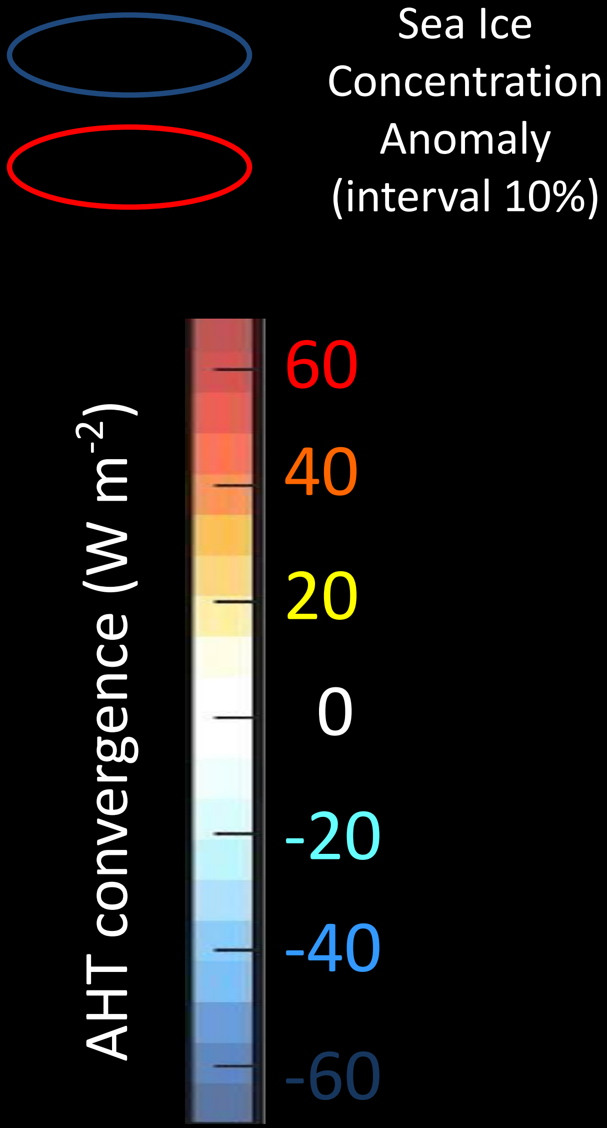
⬭ ⬭ Sea Ice
Concentration
Anomaly
(interval 10%)



Temporal evolution of AHT associated with (2σ) sea ice loss events in CESM1 – wintertime

AHT 8 days before

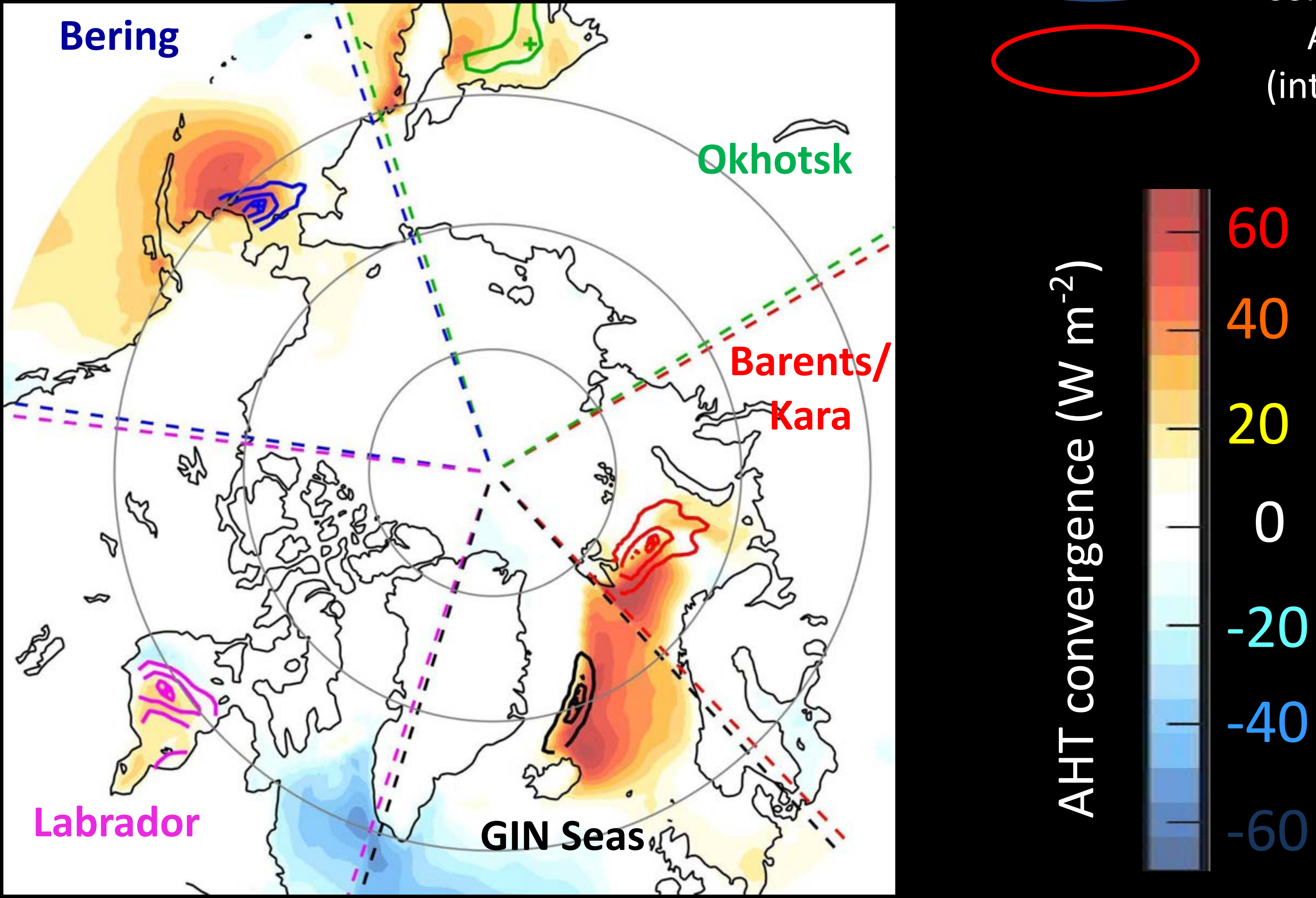




Temporal evolution of AHT associated with (2σ) sea ice loss events in CESM1 – wintertime

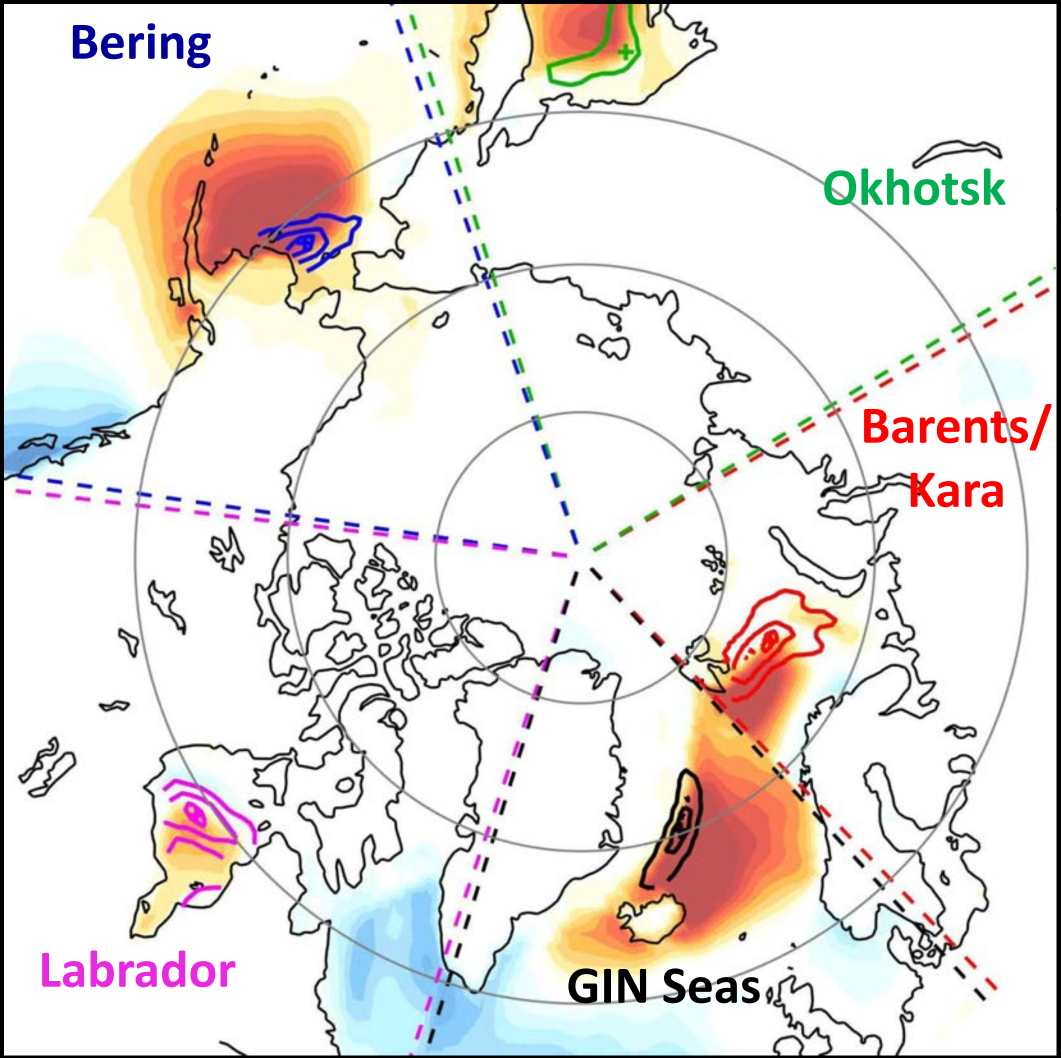
AHT 6 days before

Sea Ice Concentration Anomaly (interval 10%)

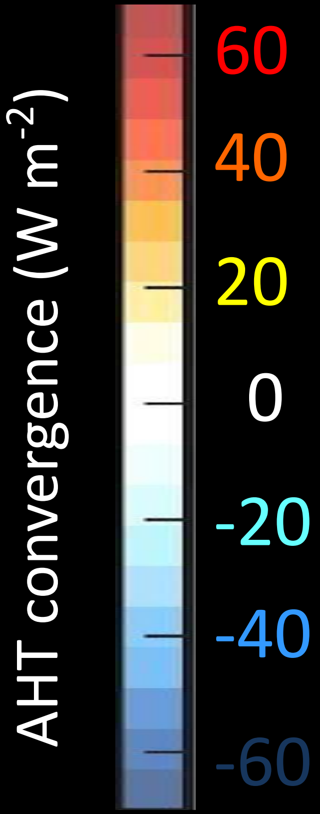


Temporal evolution of AHT associated with (2σ) sea ice loss events in CESM1 – wintertime

AHT 4 days before

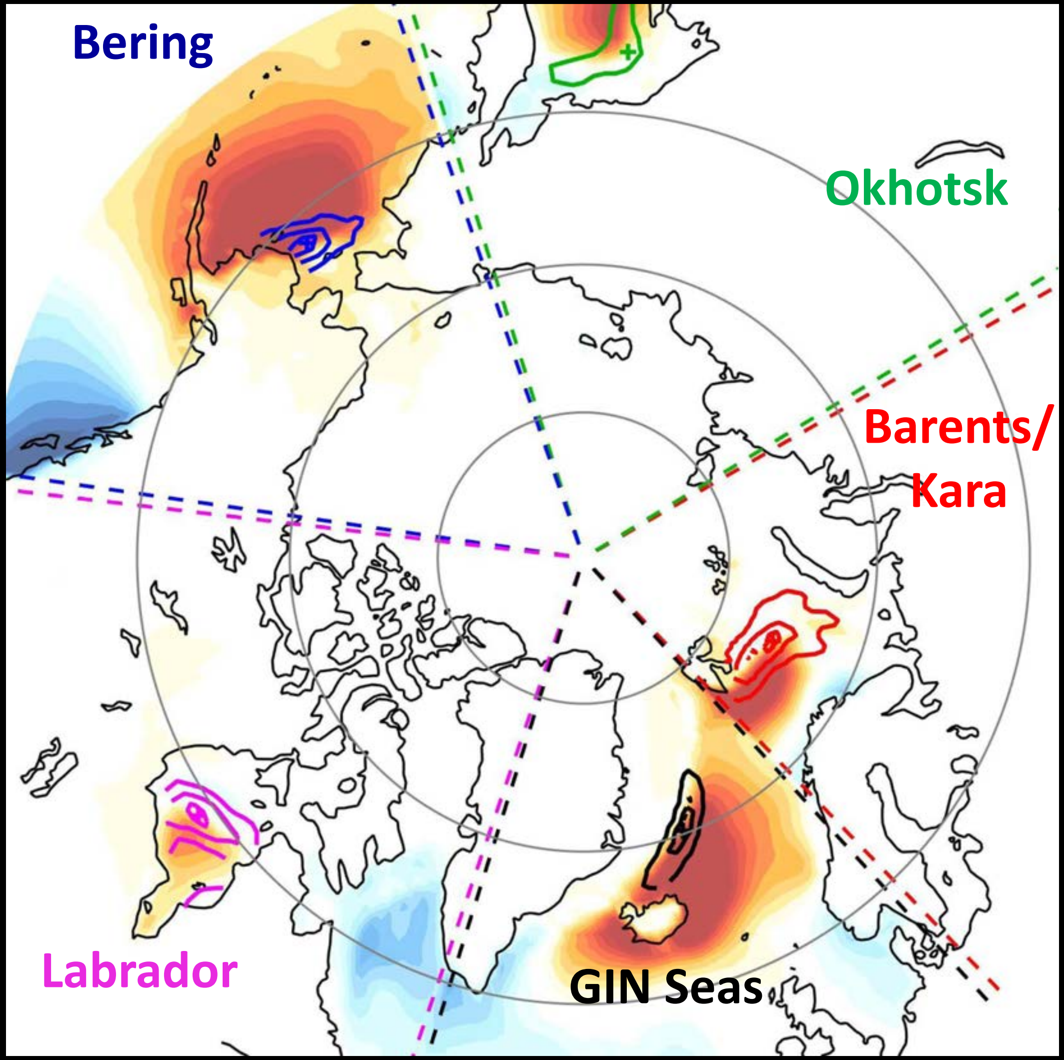


Sea Ice Concentration Anomaly (interval 10%)

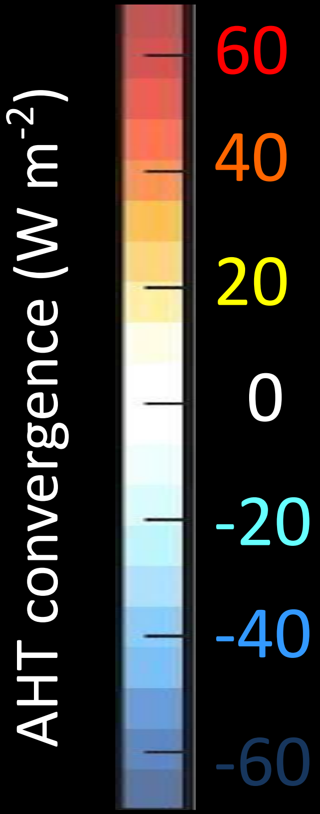


Temporal evolution of AHT associated with (2σ) sea ice loss events in CESM1 – wintertime

AHT 2 days before

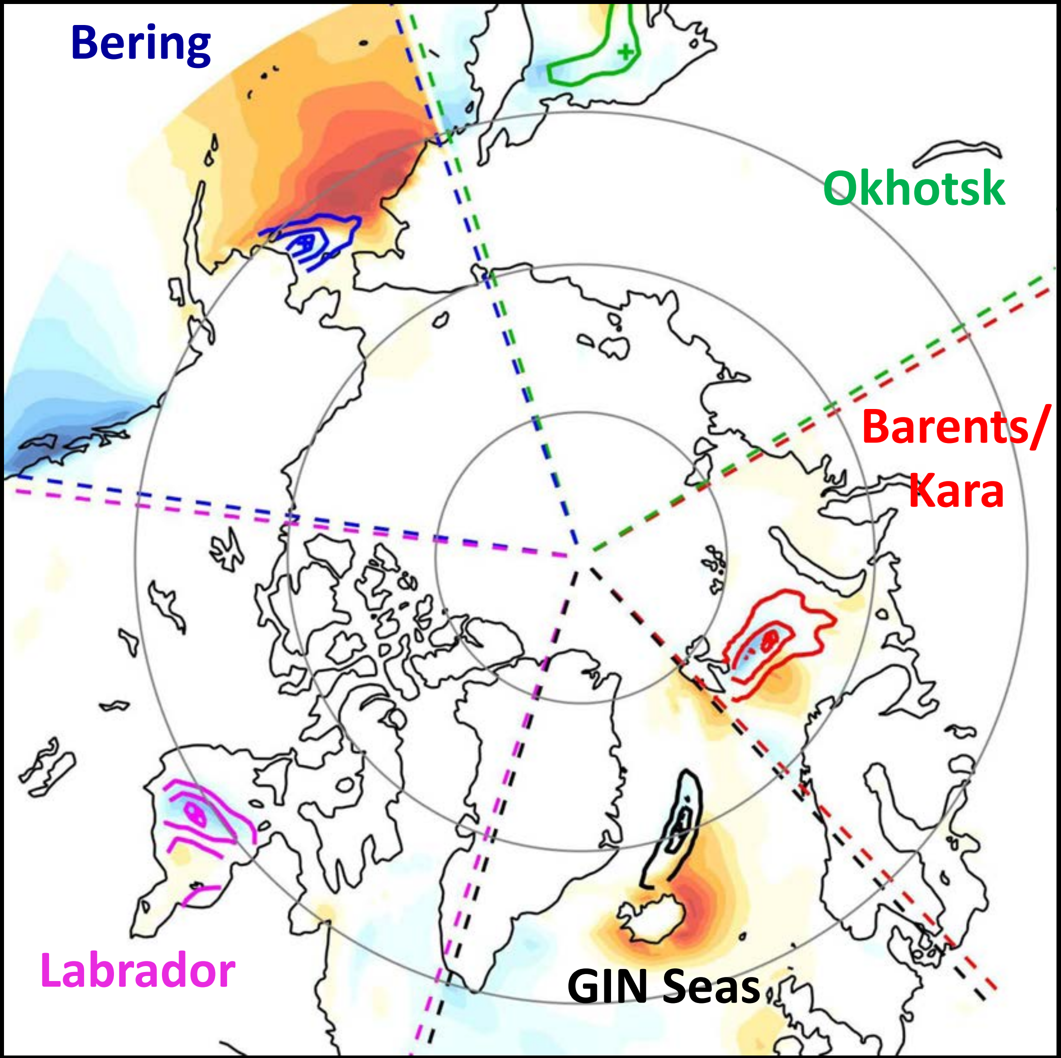


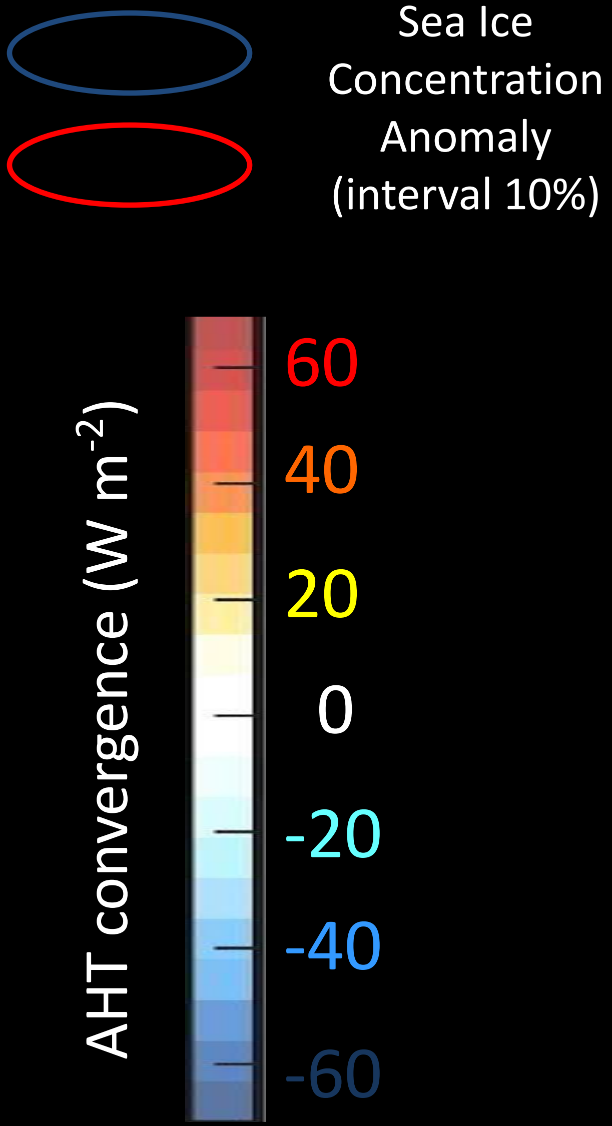
Sea Ice
Concentration
Anomaly
(interval 10%)



Temporal evolution of AHT associated with (2σ) sea ice loss events in CESM1 – wintertime

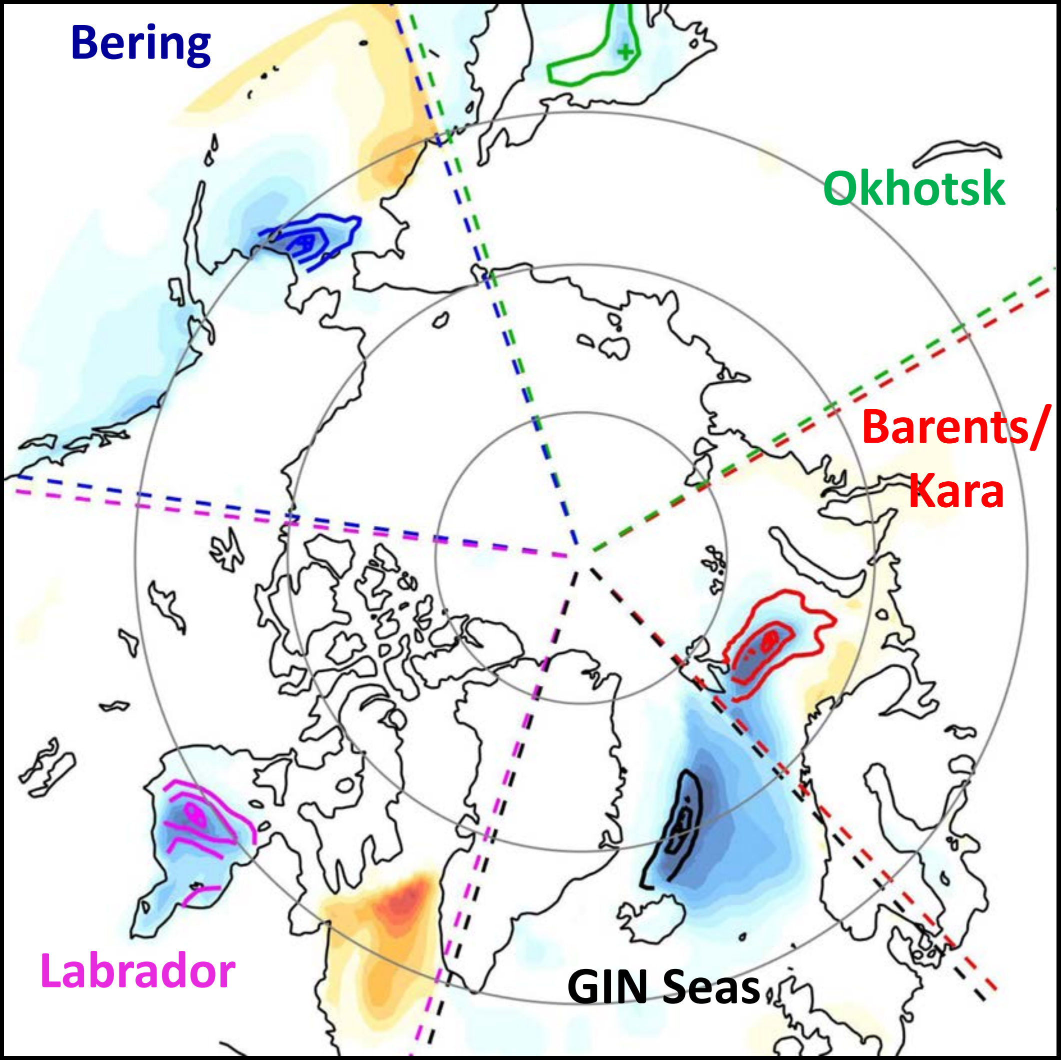
AHT during





Temporal evolution of AHT associated with (2σ) sea ice loss events in CESM1 – wintertime

AHT 2 days after



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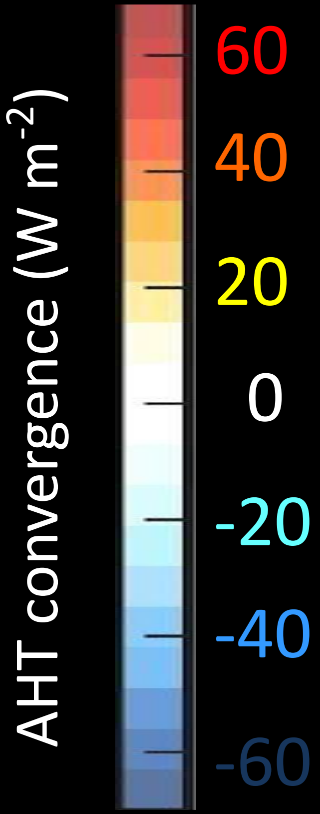

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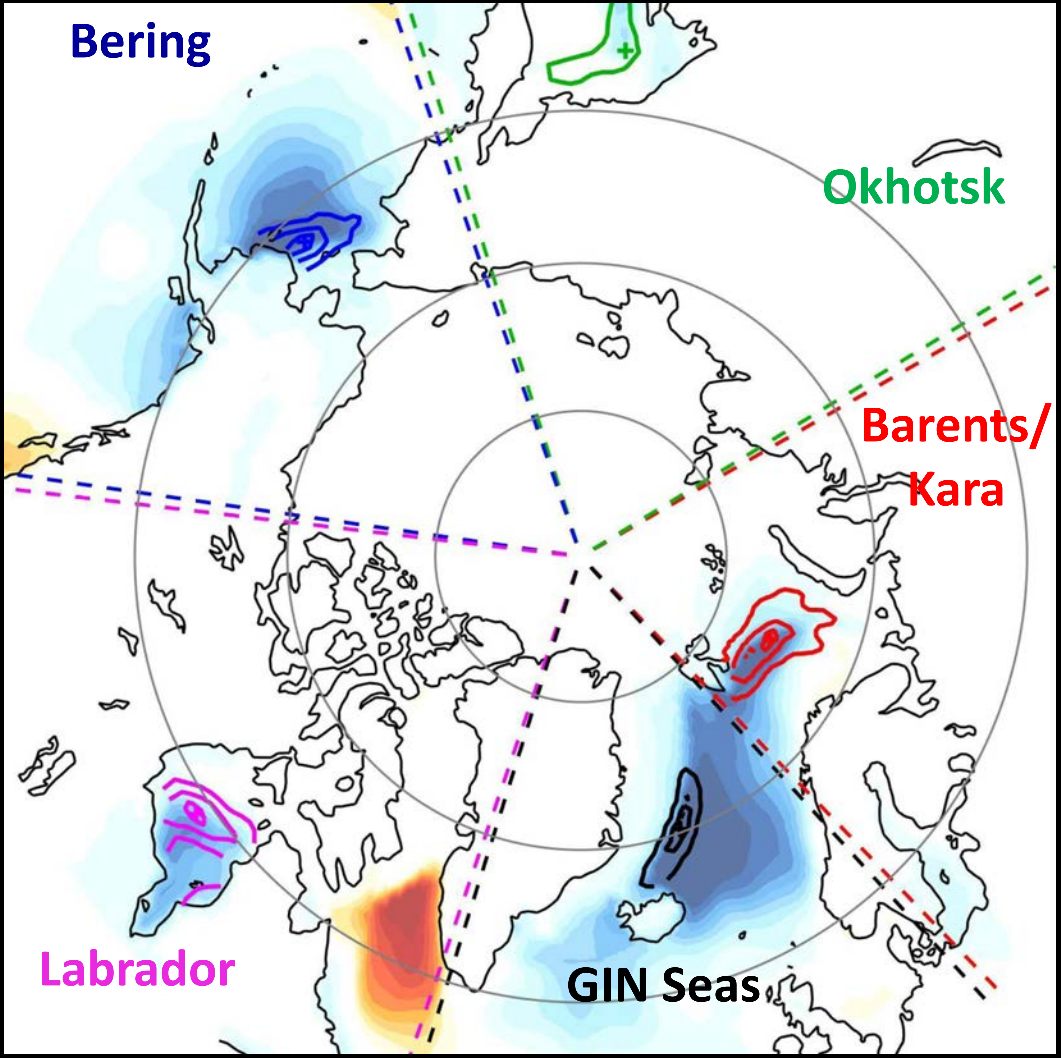
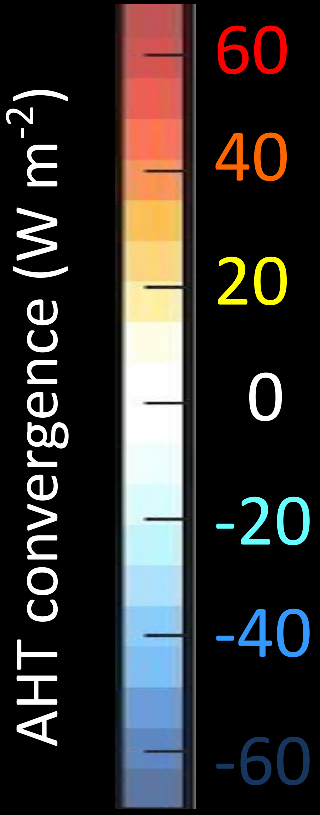
AHT 4 days after



Sea Ice Concentration Anomaly (interval 10%)



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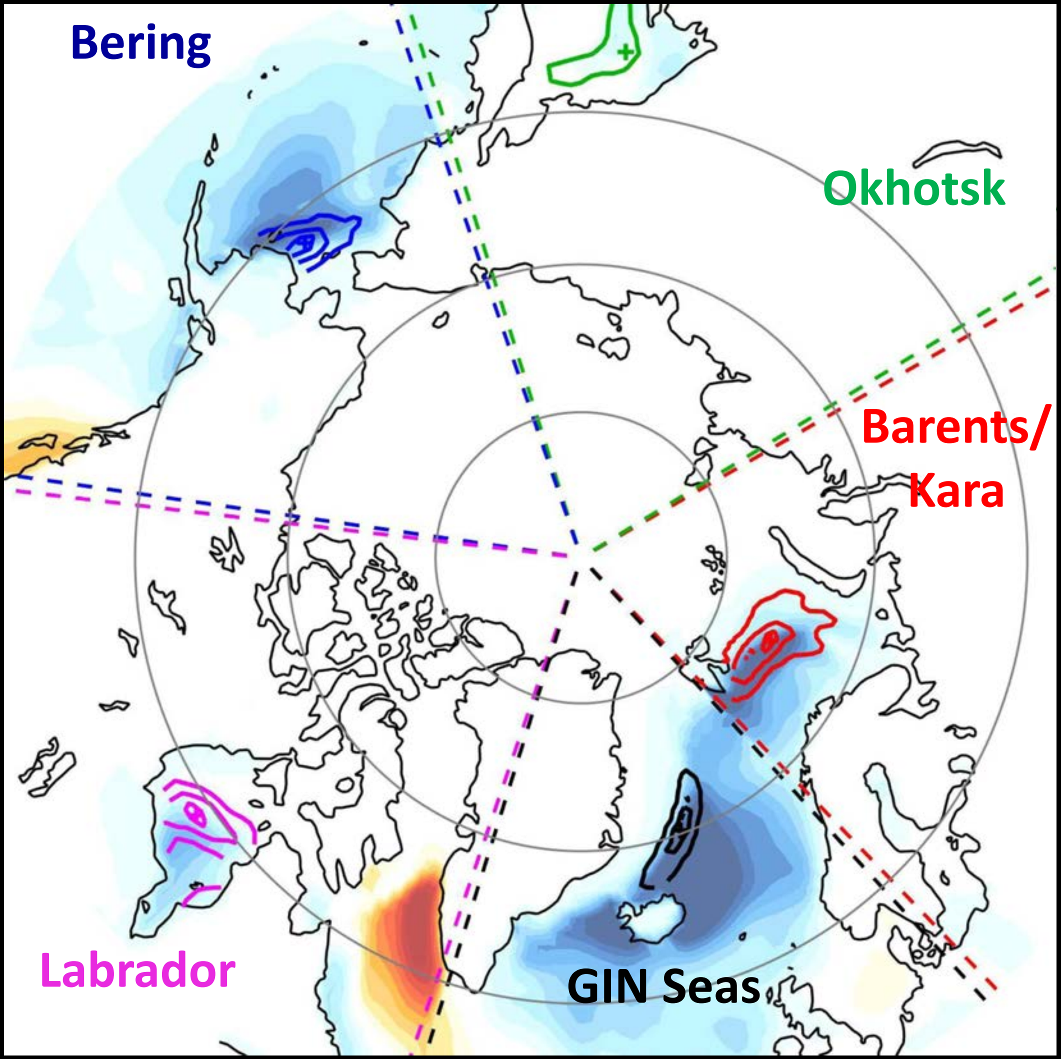
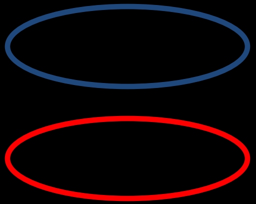
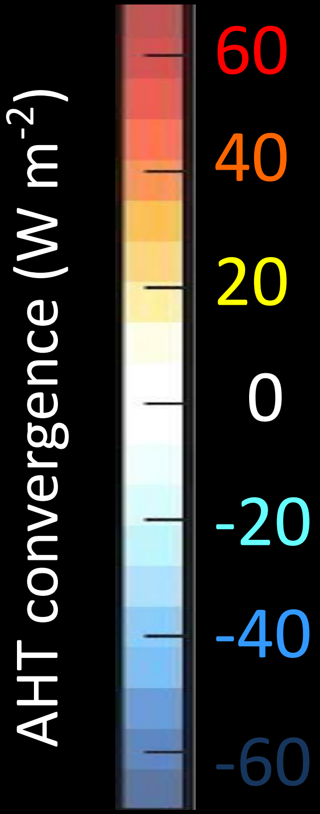
AHT 6 days after





Sea Ice
Concentration
Anomaly
(interval 10%)



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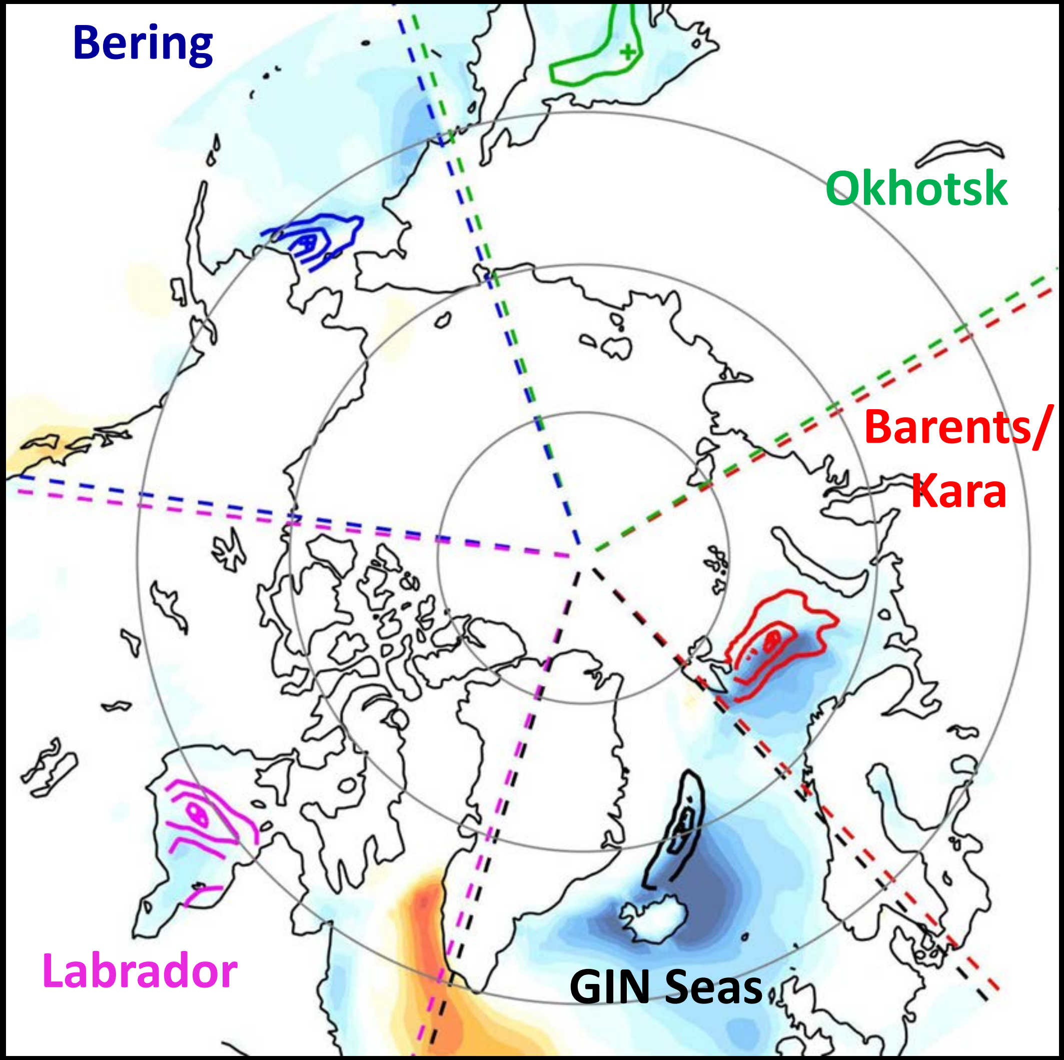

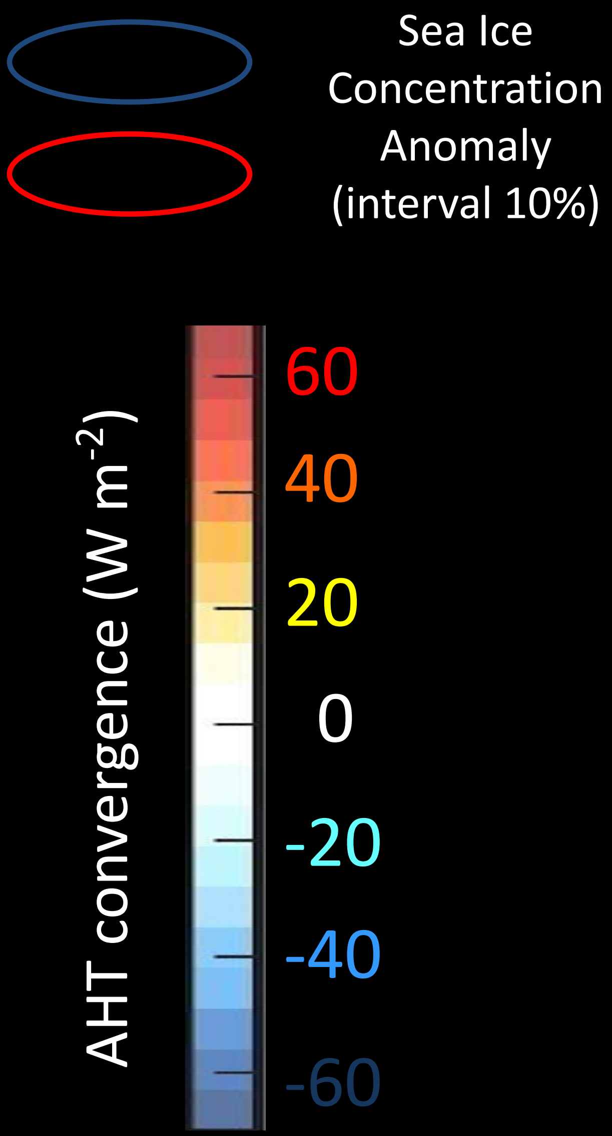

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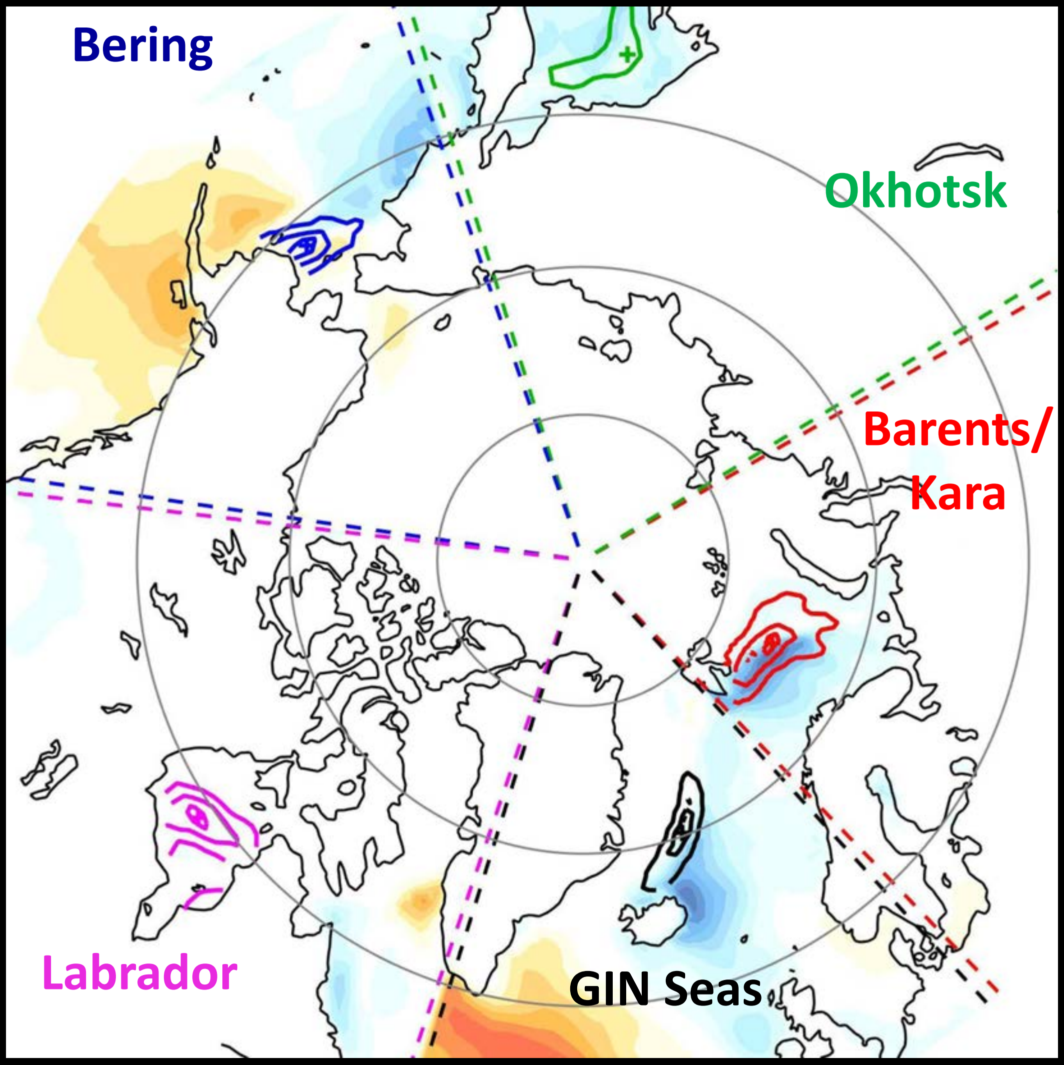
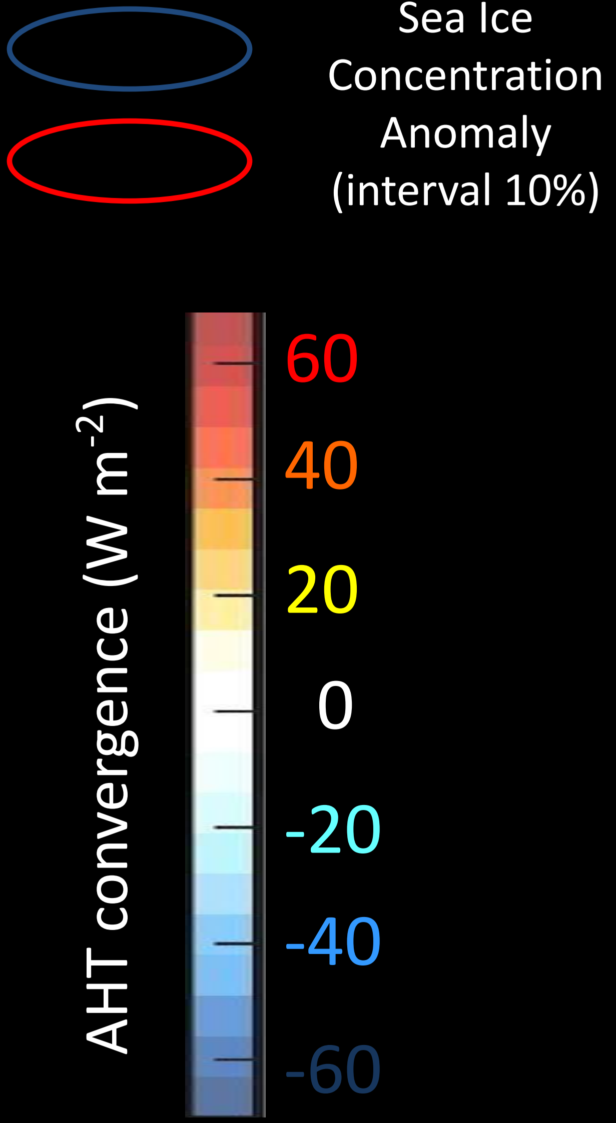
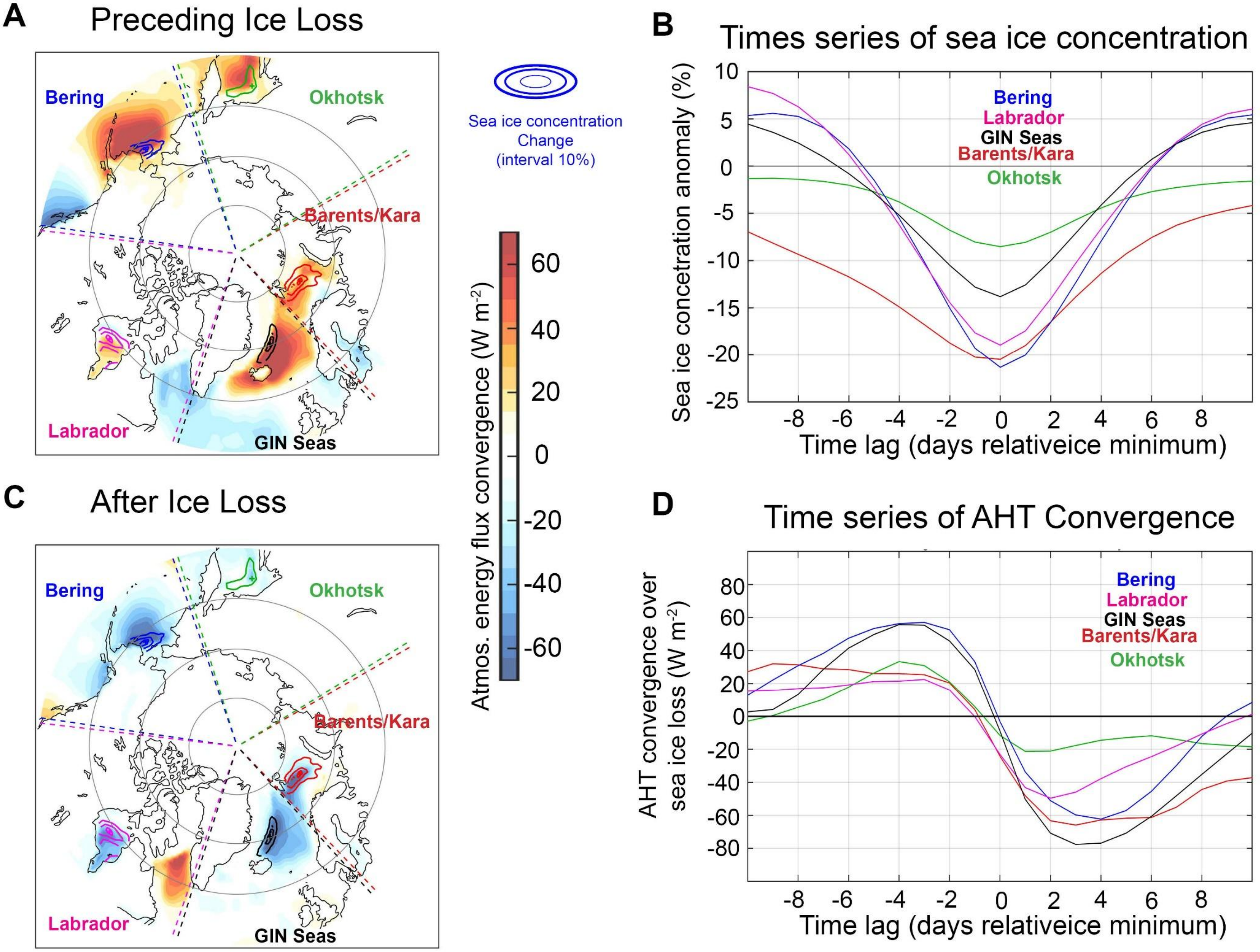


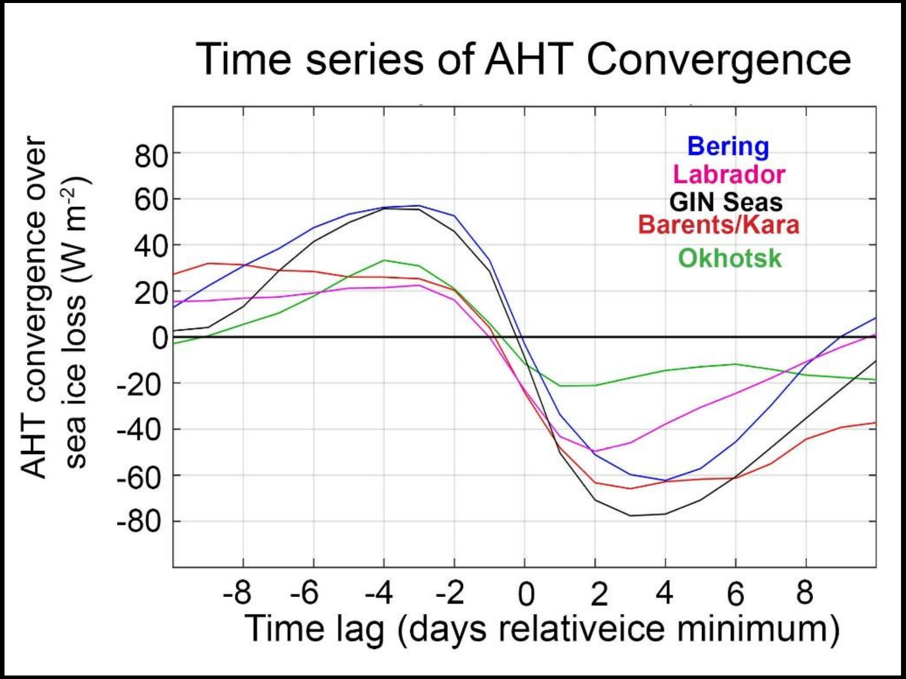



A
Preceding Ice Loss
Bering
Okhotsk
Barents/Kara
Labrador
GIN Seas
Sea ice concentration Change (interval 10%)
Atmos. energy flux convergence (W m^{-2})
60
40
20
0
-20
-40
-60
B
Times series of sea ice concentration
Sea ice concetration anomaly (%)
10
5
0
-5
-10
-15
-20
-25
Bering
Labrador
GIN Seas
Barents/Kara
Okhotsk
-8
-6
-4
-2
0
2
4
6
8
Time lag (days relativeice minimum)
C
After Ice Loss
Bering
Okhotsk
Barents/Kara
Labrador
GIN Seas
D
Time series of AHT Convergence
AHT convergence over sea ice loss (W m^{-2})
80
60
40
20
0
-20
-40
-60
-80
Bering
Labrador
GIN Seas
Barents/Kara
Okhotsk
-8
-6
-4
-2
0
2
4
6
8
Time lag (days relativeice minimum)

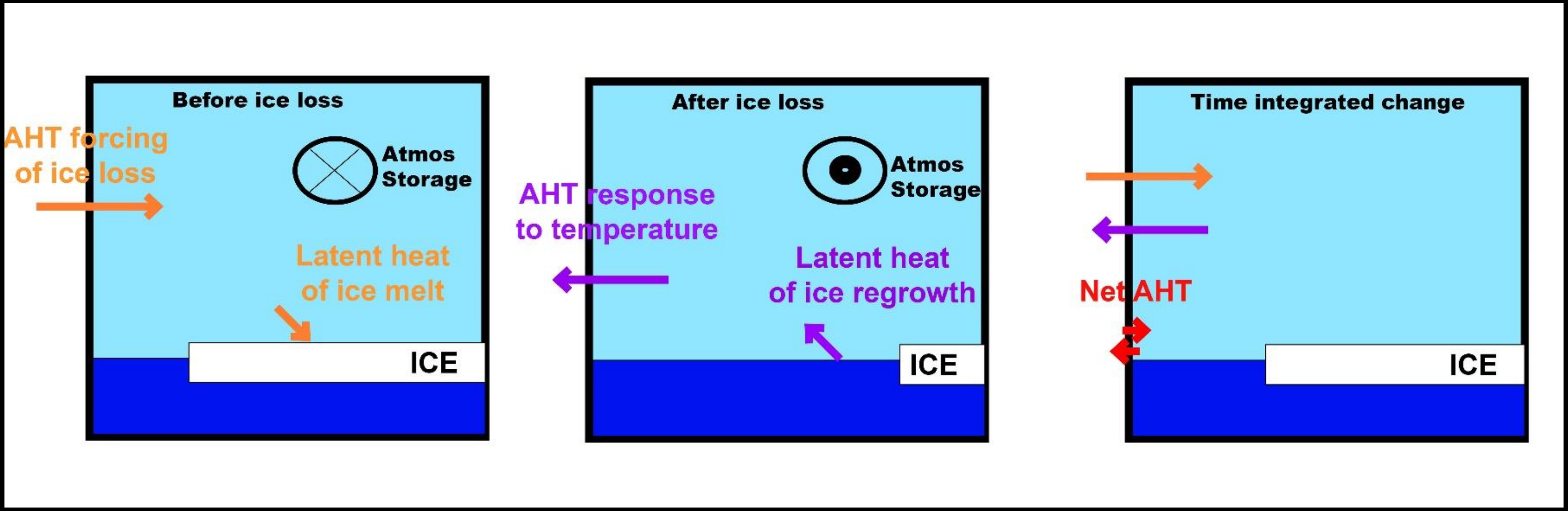
Pulse of atmospheric heat transport precedes sea ice loss

- Heats the atmosphere (80%) and melts ice (20%)

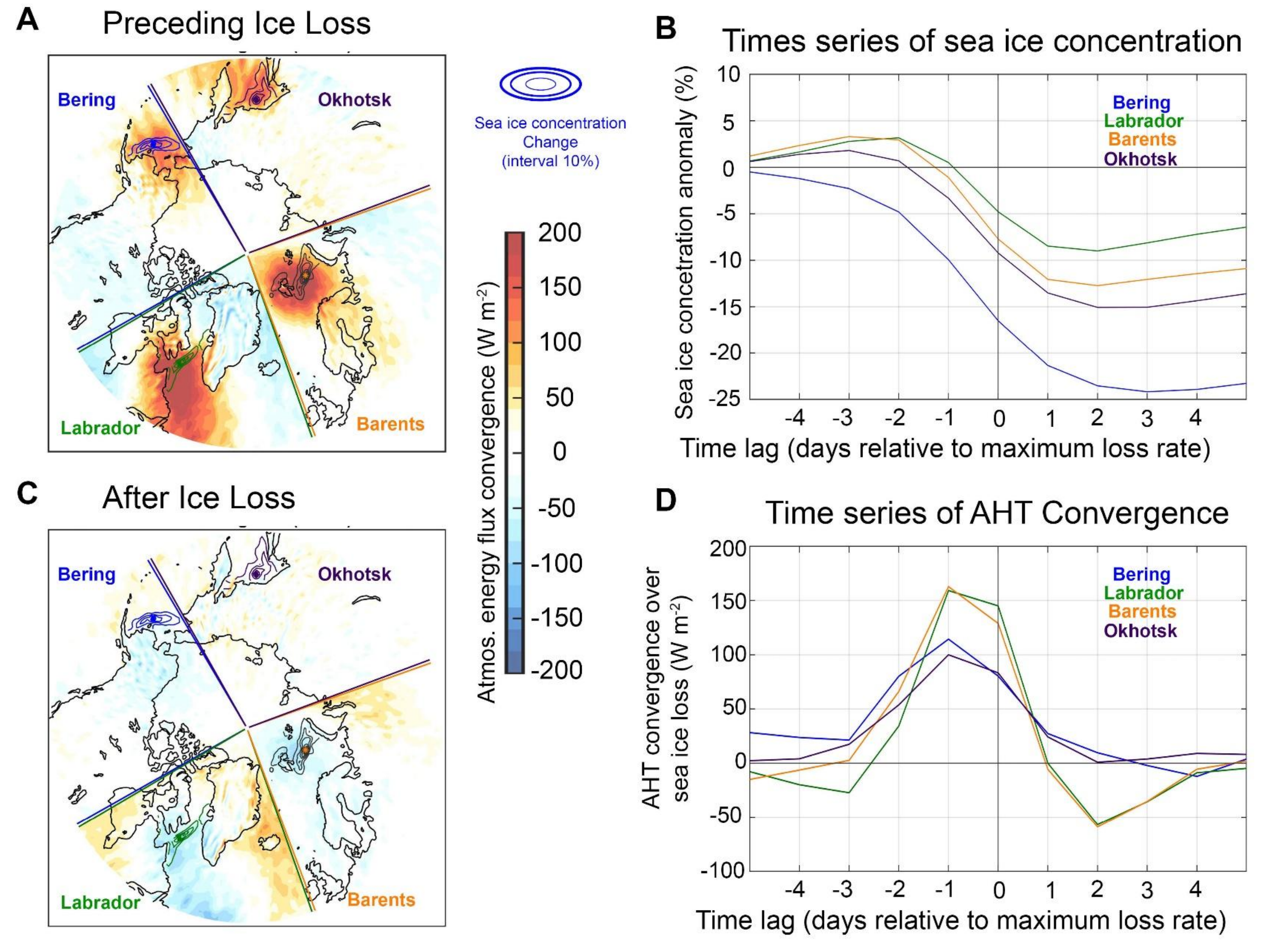
After ice melt and warming, the atmosphere exports energy from the region



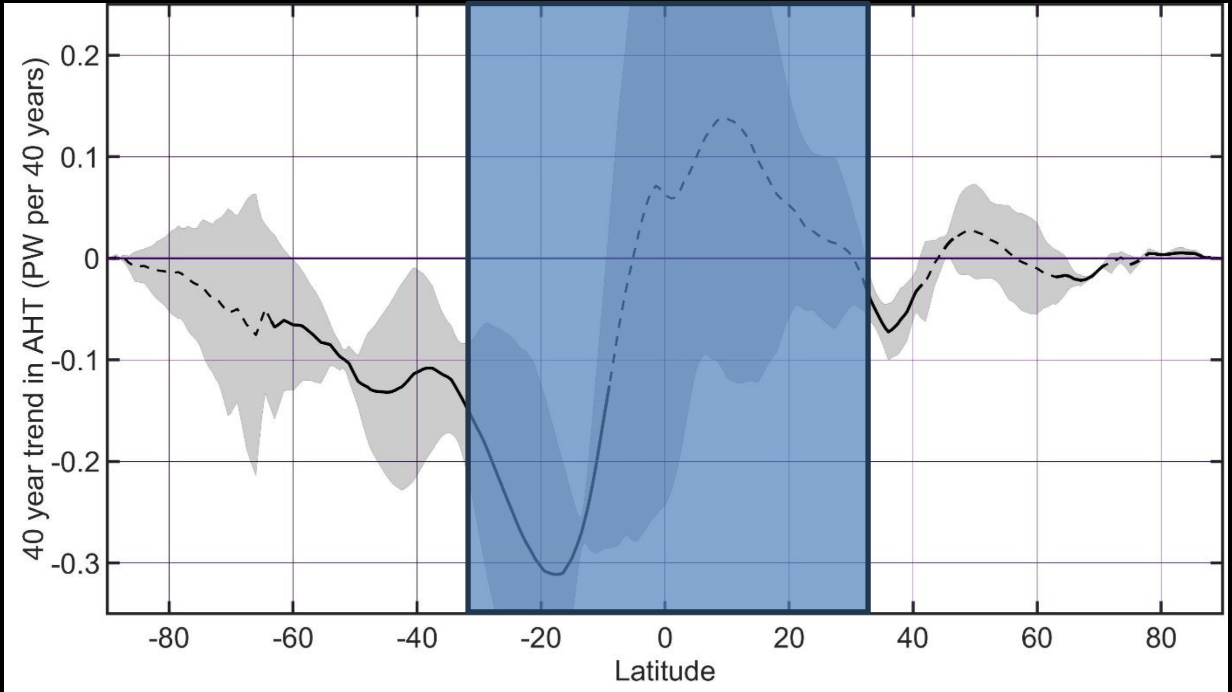
The time integrated change in heat transport is near zero



Observational relationship between AHT and sea ice loss



Trends in Atmospheric Heat transport

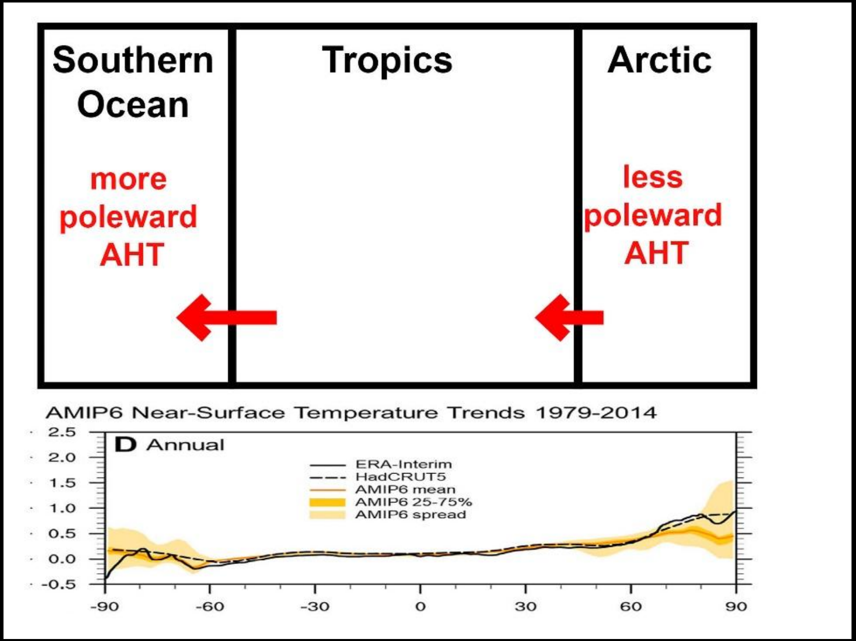


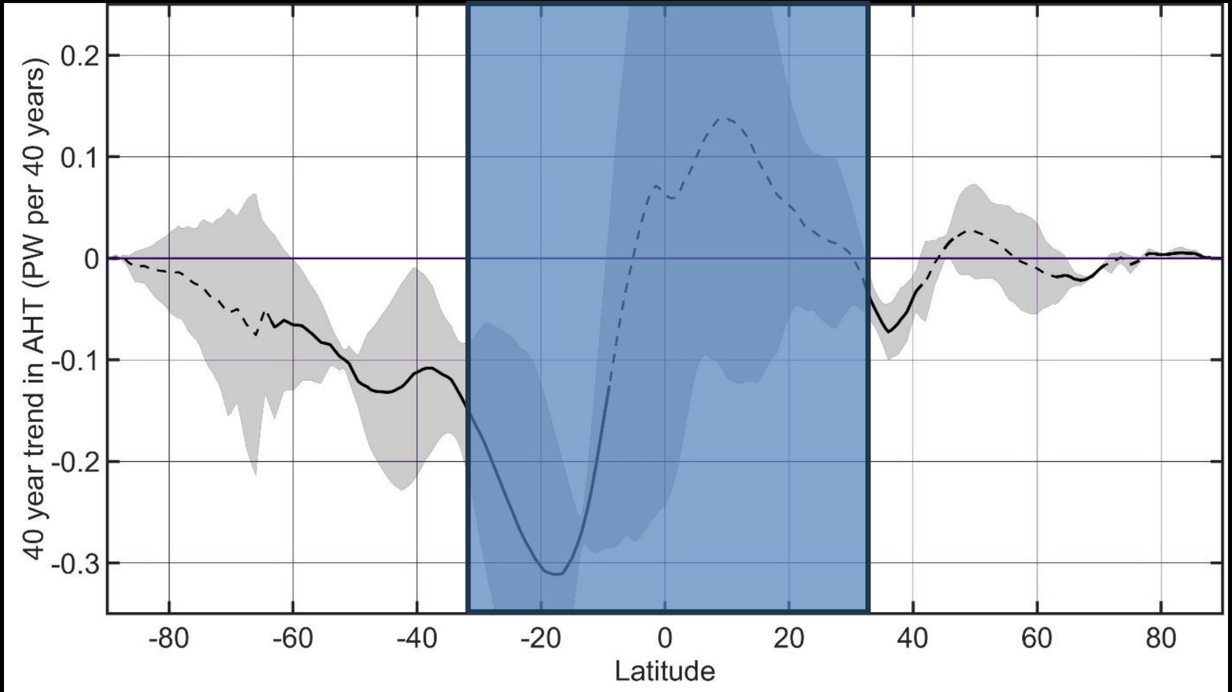
40-year trends in AHT across 4 sets of reanalysis (Tyler Cox)

- Trends are only marginally significant

Extratropical trends are consistent with diffusion of energy down the gradient of surface temperature change

- Delayed Southern Ocean warming and increased poleward AHT into the Southern Ocean
- Arctic amplification and reduced poleward AHT into the Arctic





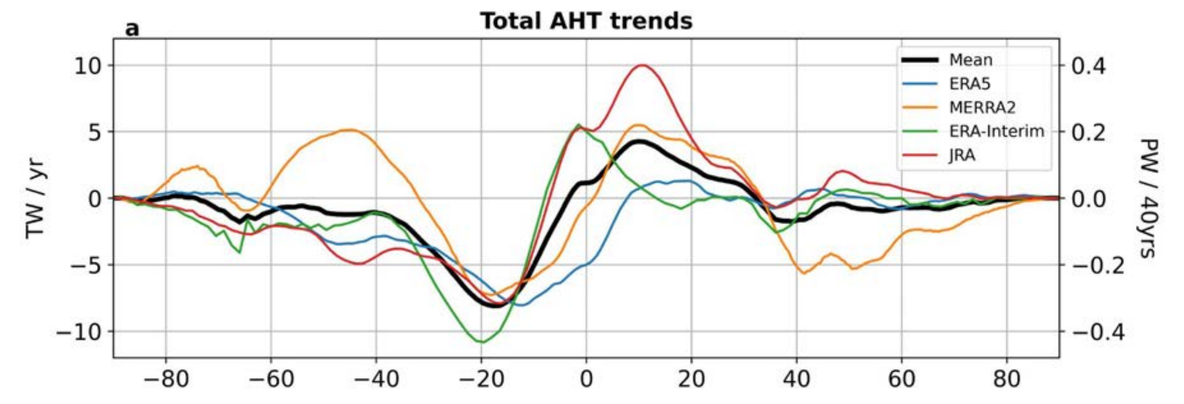
Trends in Atmospheric Heat transport

40-year trends in AHT across 4 sets of reanalysis (Tyler Cox)

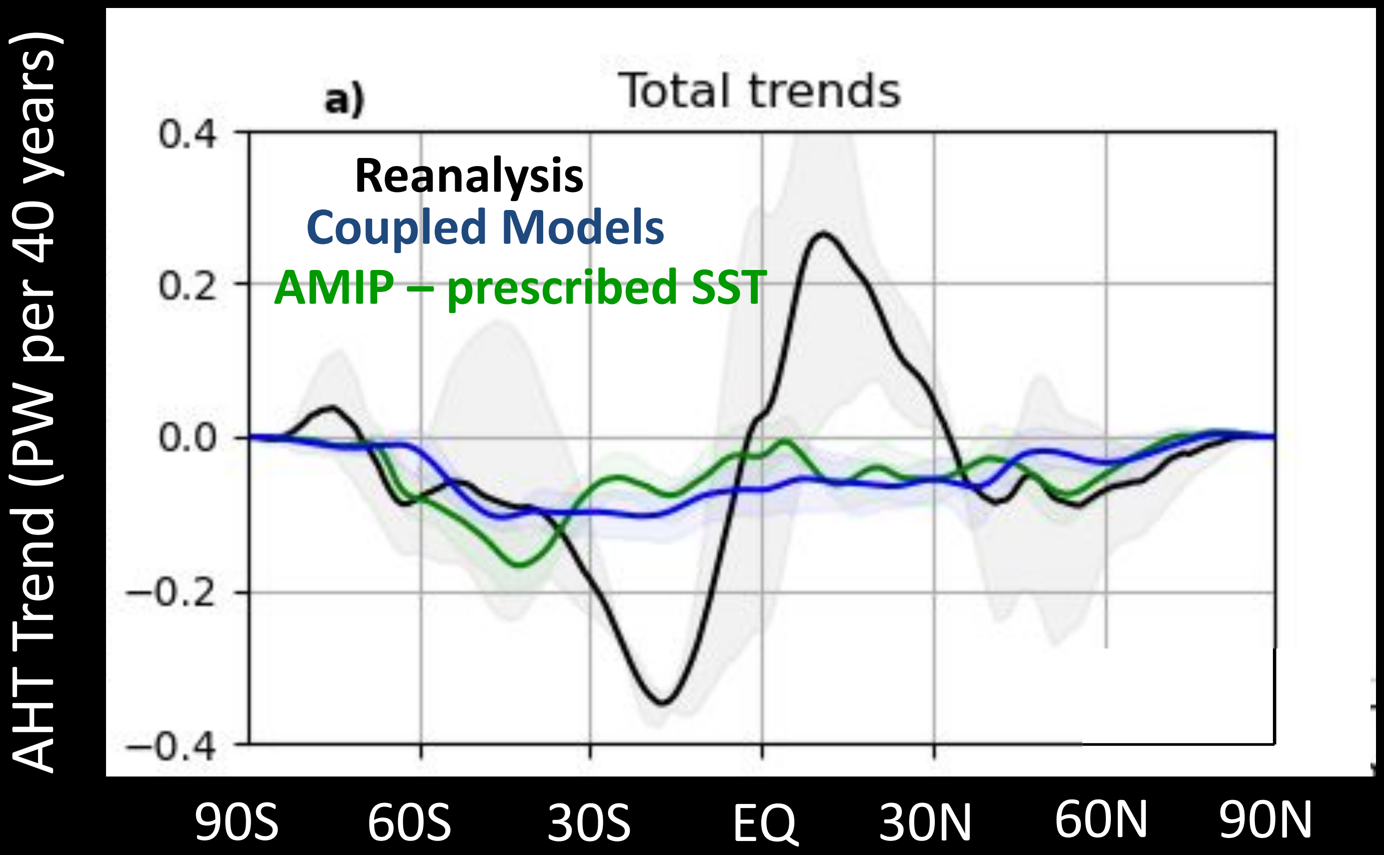
□ Trends are only marginally significant

Emphasis: trends differ
between reanalysis

Are there lesson to be learned?



Do models simulate the AHT trends?



Observed tropical trends are unrealistic due to unrealistic precipitation trends in reanalysis (Chemke and Polvani, 2019)

Prescribed SST simulations better match the observations compared to fully coupled simulations

Partitioning of atmospheric energy by circulation type

$$AHT(\phi) = -\frac{2\pi a\cos(\phi)}{g}\int_{p_s}^{0} \underbrace{[\bar{V}][\overline{MSE}]}_{MOC} + \underbrace{\overline{[V]'[MSE]'}}_{TOC} + \underbrace{[V^{*}MSE^{*}]}_{Stat.eddy} + \underbrace{\overline{[V^{*\prime}MSE^{*\prime}]}}_{Trans.eddy}\, dp$$

* = Departure from zonal mean -- [ ]

' = Departure from time mean -- ¯

MSE = moist static energy

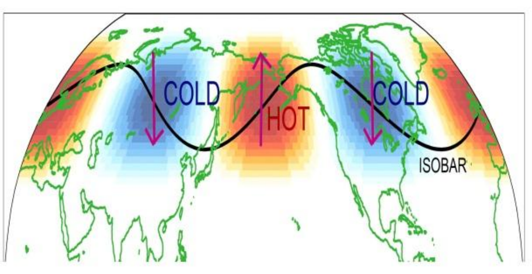
= CpT + LQ +gZ

MOC dominates in the deep tropics – Hadley cell

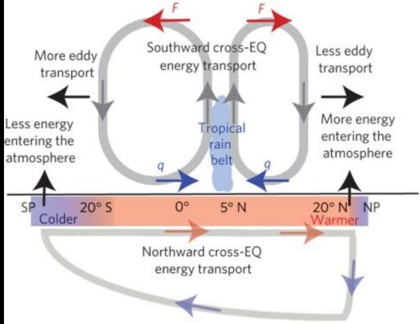
Stationary eddies stronger in NH

Transient eddies dominate the mid-latitudes

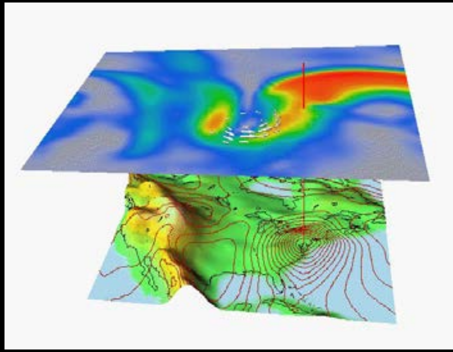
Stationary

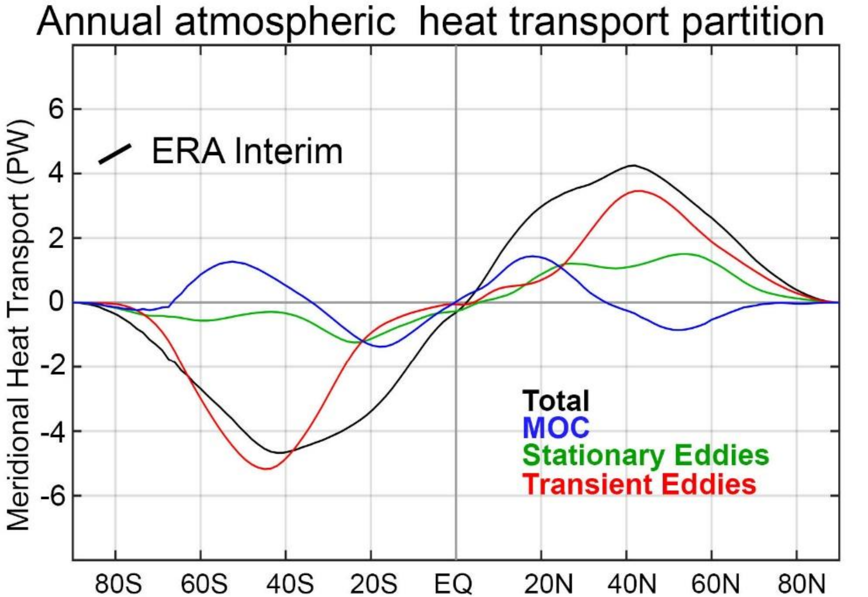


MOC Overturning

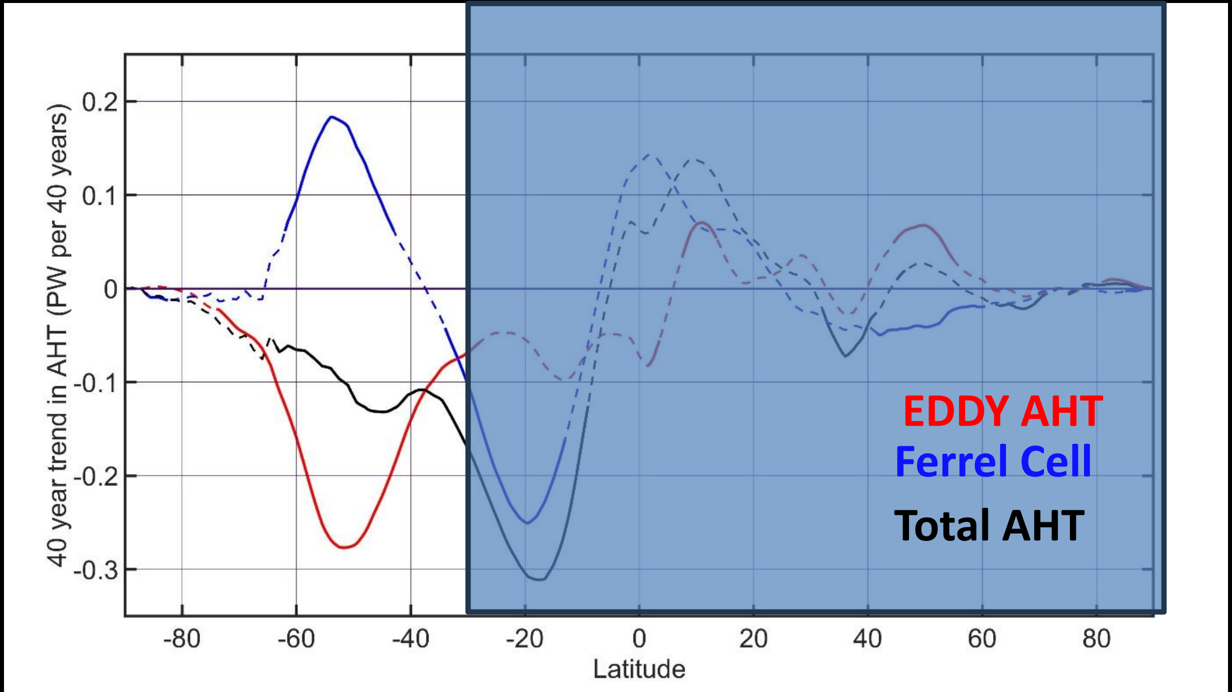


Transient



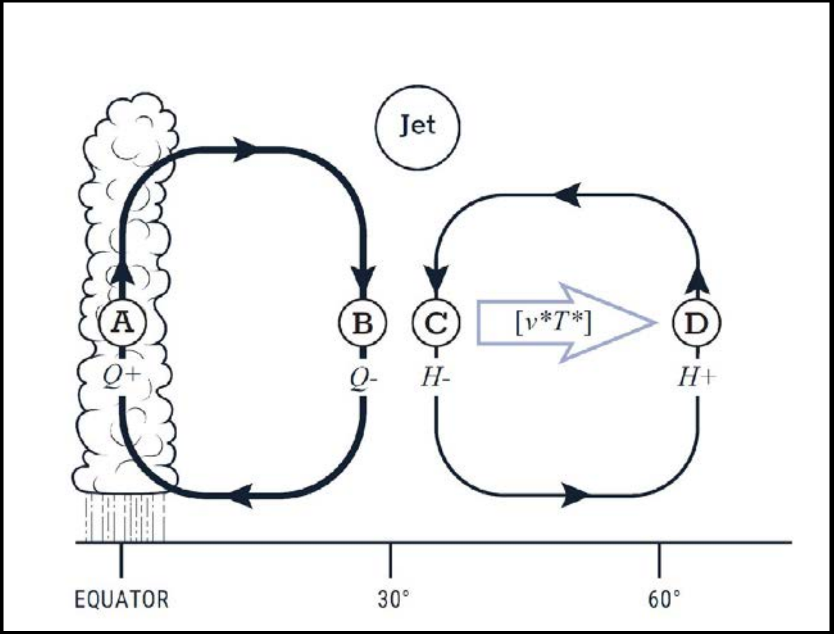


Partitioning of trends in Atmospheric Heat transport

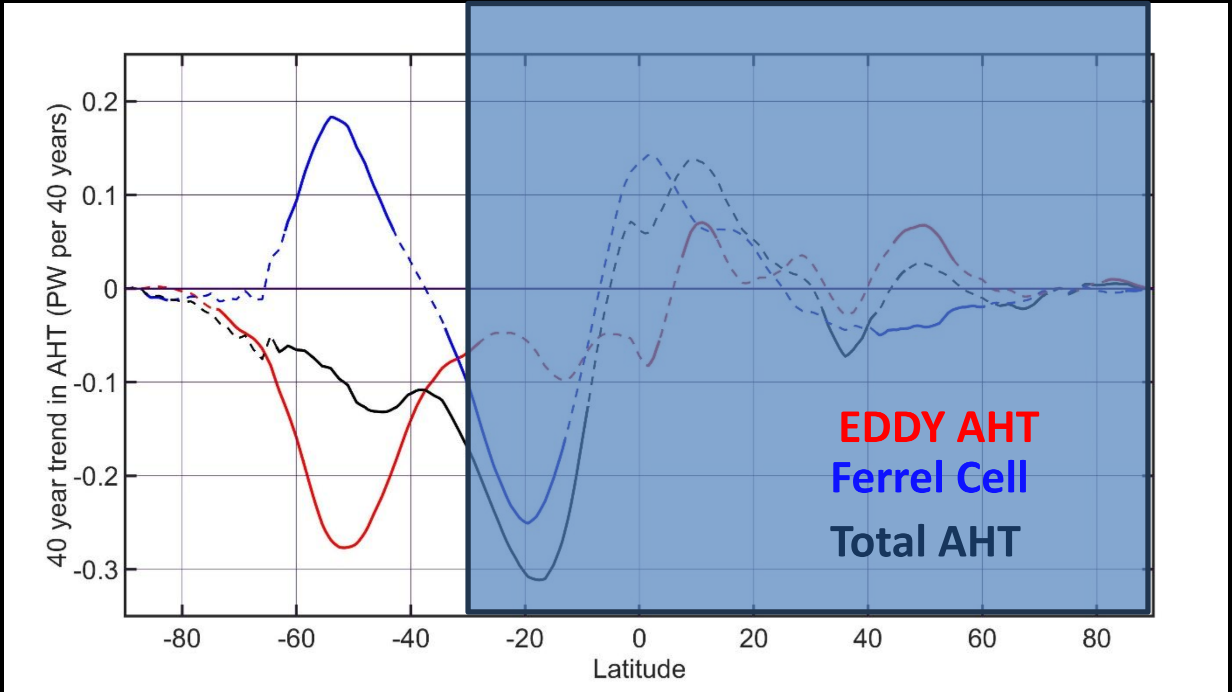


Changes in Eddy AHT are (imperfectly) compensated by changes in Ferrel Cell AHT

Anomaly in eddy AHT convergence (at 60S) forces ascent and strengthening of Ferrel Cell



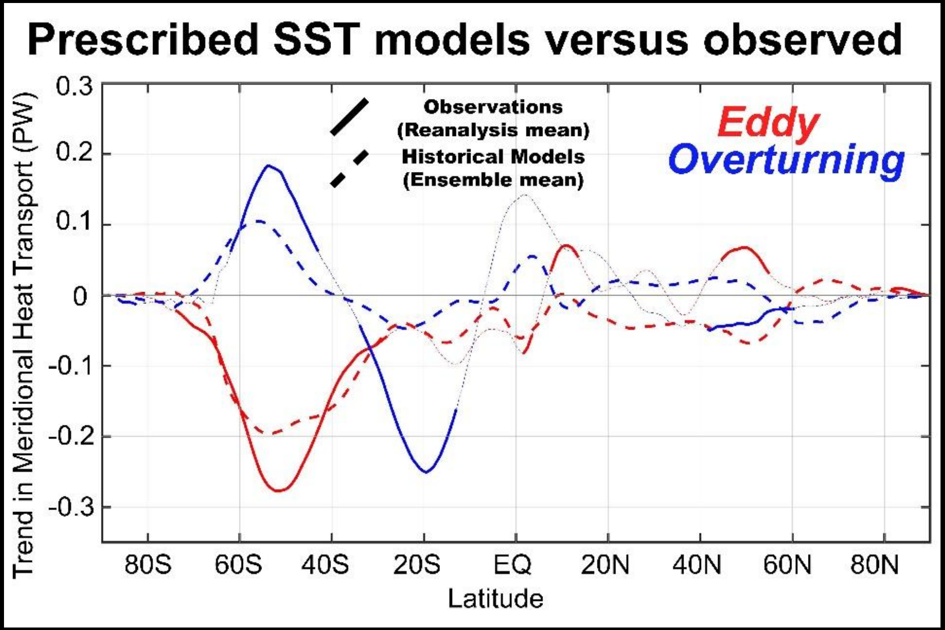
Partitioning of trends in Atmospheric Heat transport



Changes in Eddy AHT are (imperfectly) compensated by changes in Ferrel Cell AHT

AMIP models also show compensation between eddy and Ferrel cell AHT

□ Compensation is weaker so same total AHT can be achieved with less change in Eddy AHT

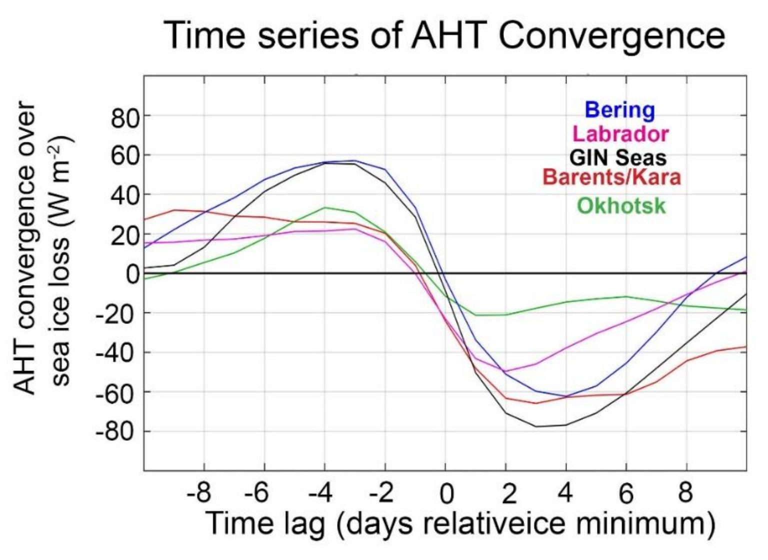


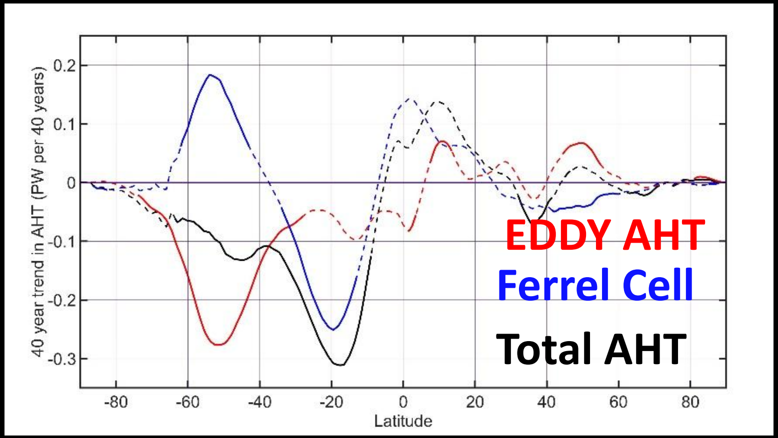
Conclusions

Changes in atmospheric heat transport into the polar regions reflect competing influence from low latitude moistening and polar amplified warming

☐ These competing influences seen in the time evolution of AHT changes associated with high-frequency ice loss events

☐ Small changes in AHT do not imply AHT is not important for polar amplification





Observed AHT trends are small due to compensating changes in Eddy and Ferrel cell AHT