Isolating the Contribution of Observed Winds to Recent Arctic Warming and Sea Ice Loss

CESM Workshop – Polar Climate Working Group

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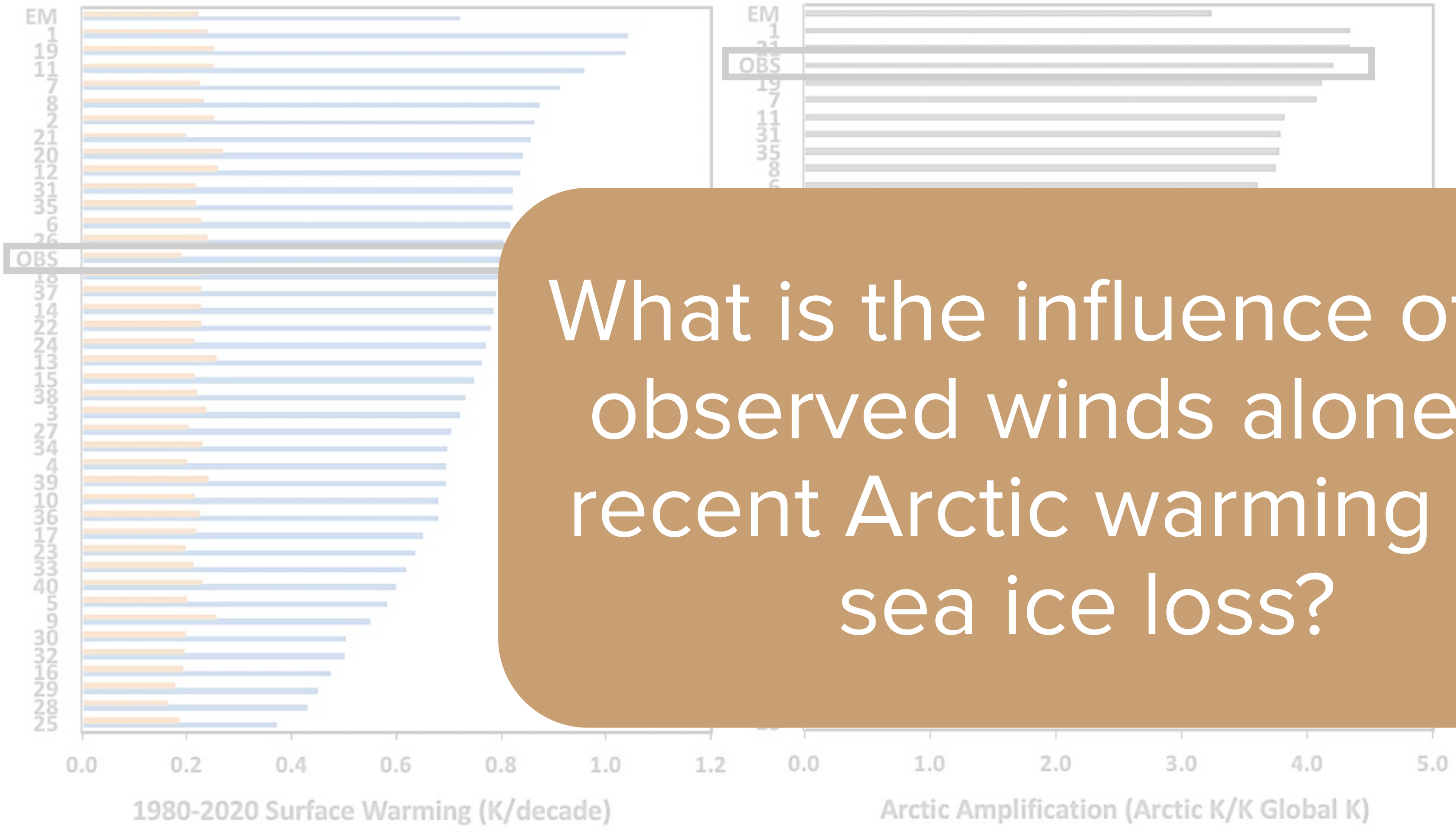
0.6 K/decade spread

2.0 Arctic Amplification factor spread



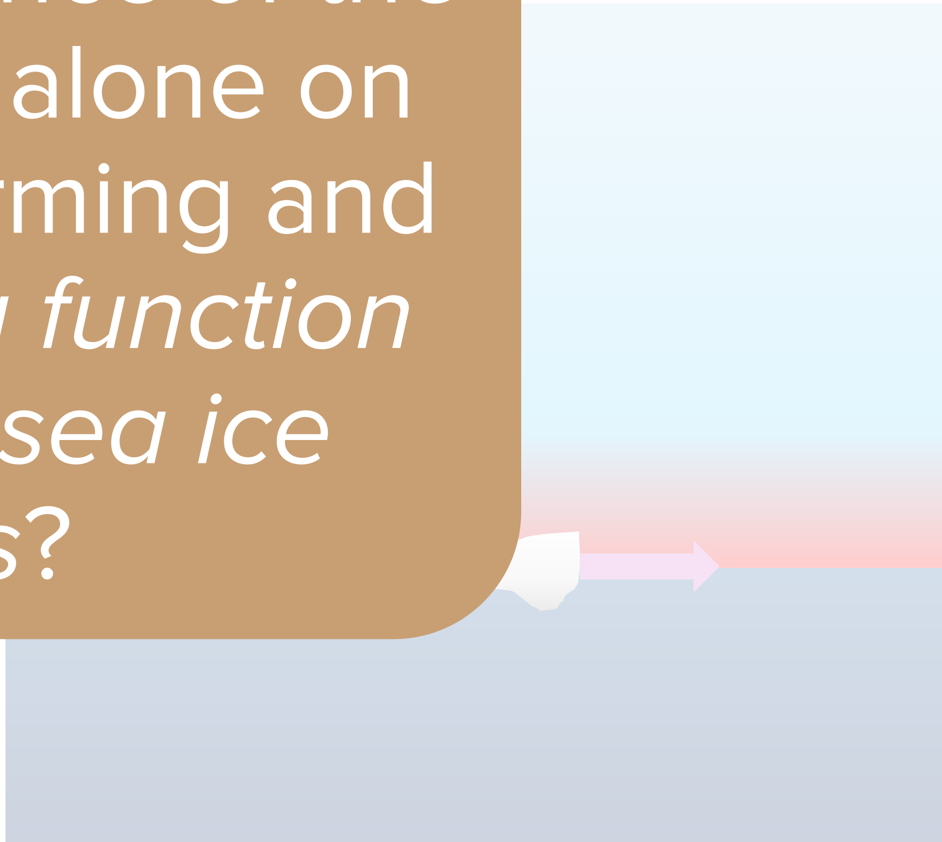
What is the influence of the observed winds alone on recent Arctic warming and sea ice loss?

Ensemble members with ...tmospheric ...ulation closer ...bservations ...eproduce ...erved sea ice ...s & warming ...er (Ding 2017, Ding 2019, Roach & Blanchard-Wrigglesworth 2022)

Figure 1. Arctic (70-90 °N) and Global warming (left) and Arctic Amplification (right). Values for individual members and ensemble mean (EM) of the CESM1 Large Ensemble (*Kay et al. 2015*) and for observations (*GISTEMP Team, 2021*).

Thicker sea ice is less responsive to winds & warming better (Holland & Stroeve 2011, Kay

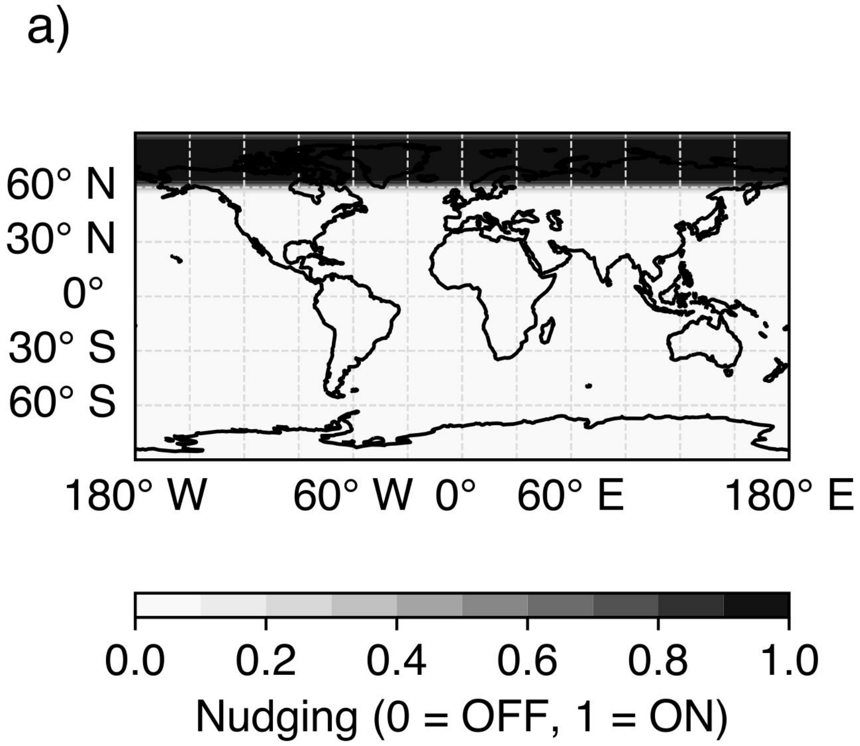
What is the influence of the observed winds alone on recent Arctic warming and sea ice loss *as a function of mean state sea ice thickness?*

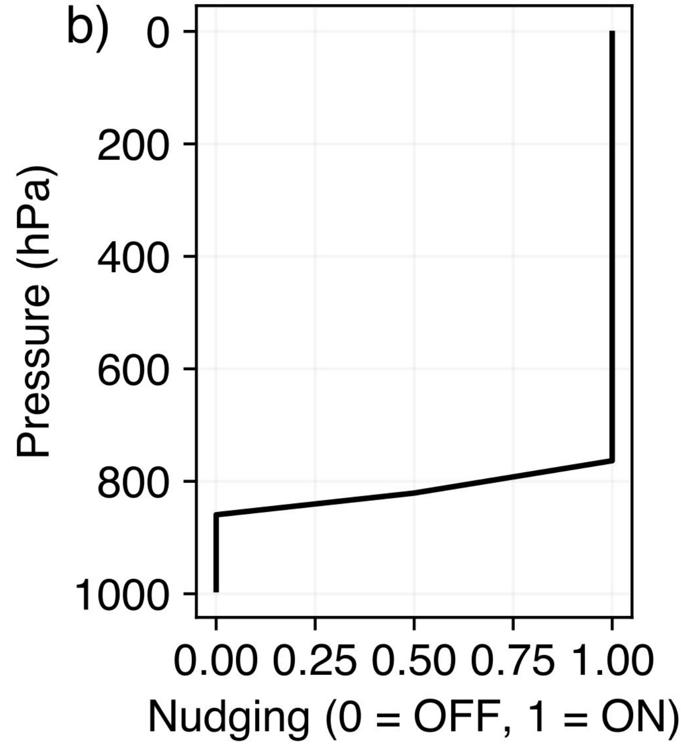


Experiment set-up

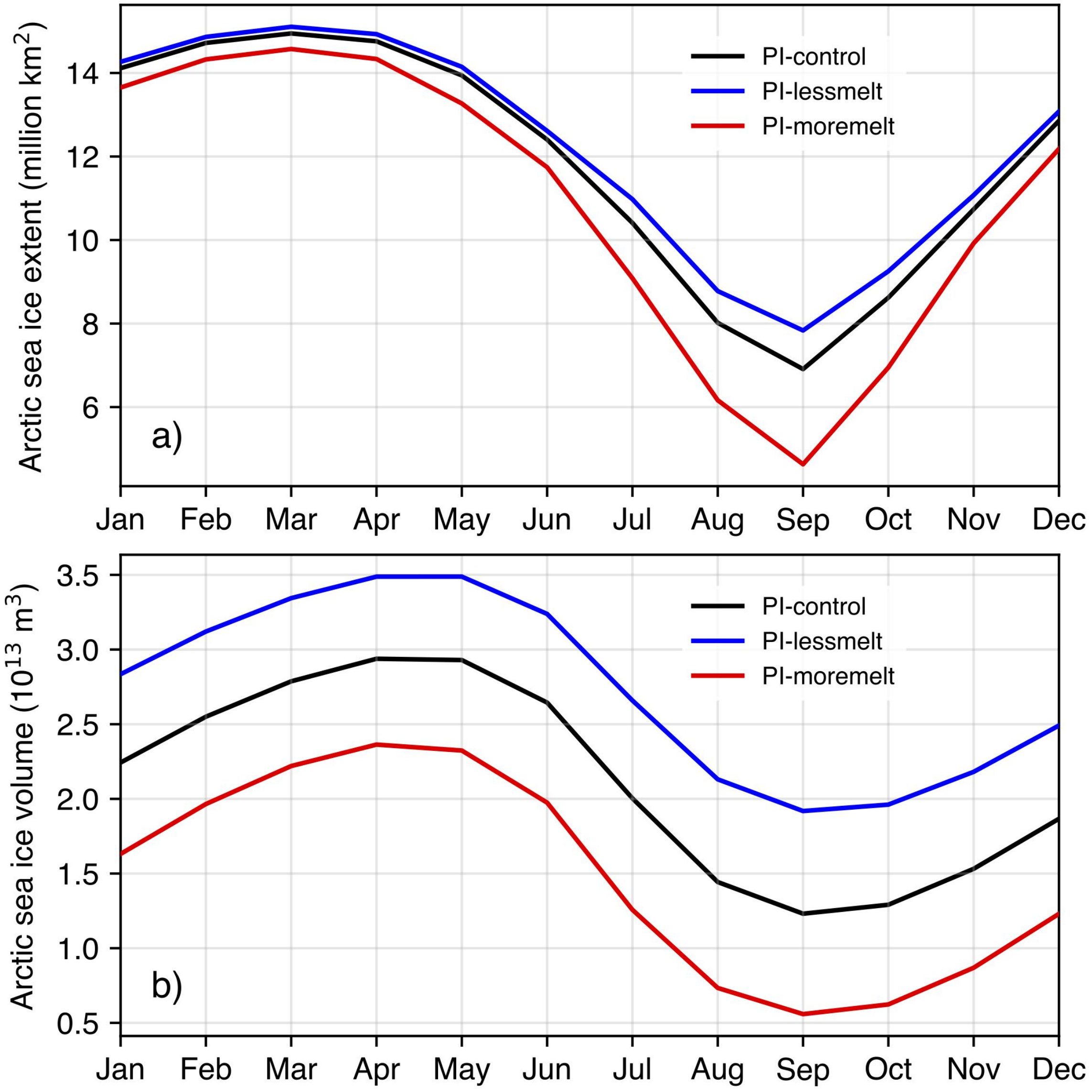
wind nudging: nudging model winds to observed winds to produce the observed circulation in a model

- CESM version 2.1.5
- Pre-industrial climate (B1850cmip6)
- Nudged model U & V wind components with 6-hourly ERA5 reanalysis from 1950-2023 for 60-90°N and above 850 hPa



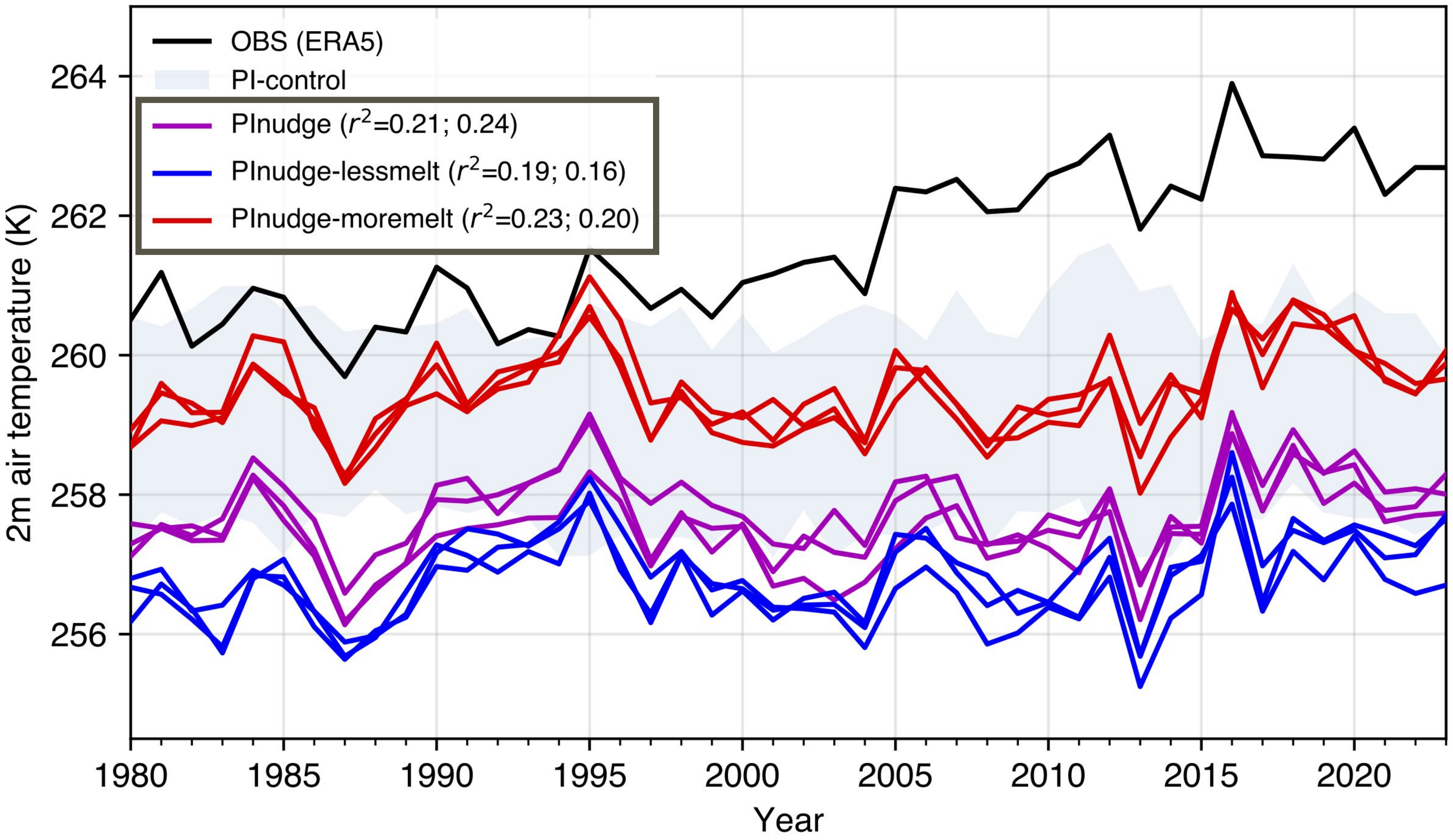


Dataset name	Ensemble members	Additional notes	Purpose
OBS	–	ERA5 for temperature & sea ice; GISTEMP for temperature anomalies only; NSIDC for sea ice	Benchmark for performance of wind-nudged experiments
PI-control	51	Sample created from 51 74-year long random slices of CESM2 pre-industrial control	Baseline for pre-industrial climate & internal variability
PInudge	3	Default wind-nudged pre-industrial climate experiment	Quantifies contribution of winds alone to observed warming & sea ice loss
PInudge-lessmelt	3	Includes sea ice lessmelt modifications generating thicker sea ice (Kay et al. 2022)	Quantifies contribution of winds plus a mean state increase in sea ice thickness
PInudge-moremelt	3	Includes sea ice moremelt modifications generating thinner sea ice (This work)	Quantifies contribution of winds plus a mean state decrease in sea ice thickness



Run name	CICE Namelist modifications	Run duration
PI-control	None – CESM2 pre-industrial control (standard r_snw = 1.25 dt_mlt = 1.5)	2,000 years
PI-lessmelt	r_snw = 1.5 dt_mlt = 1.0	550 years
PI-moremelt	r_snw = 0.0	400 years

Annual Arctic (70-90°N) temperature

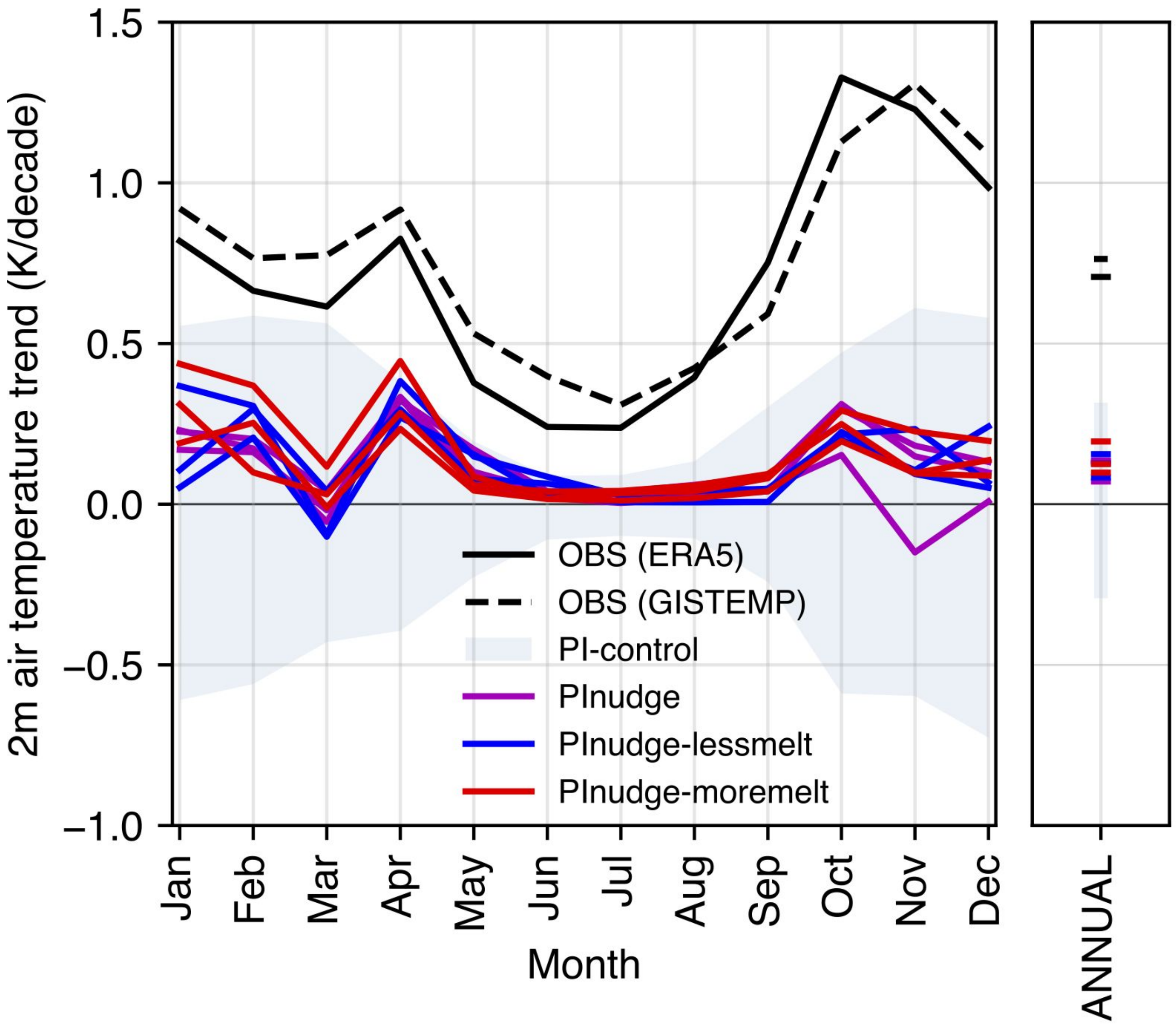


Closer to OBS ➔

Closer to PI-control ➔

Annual Arctic (70-90°N) temperature trends

30-40% in April & May



0.71 K/decade

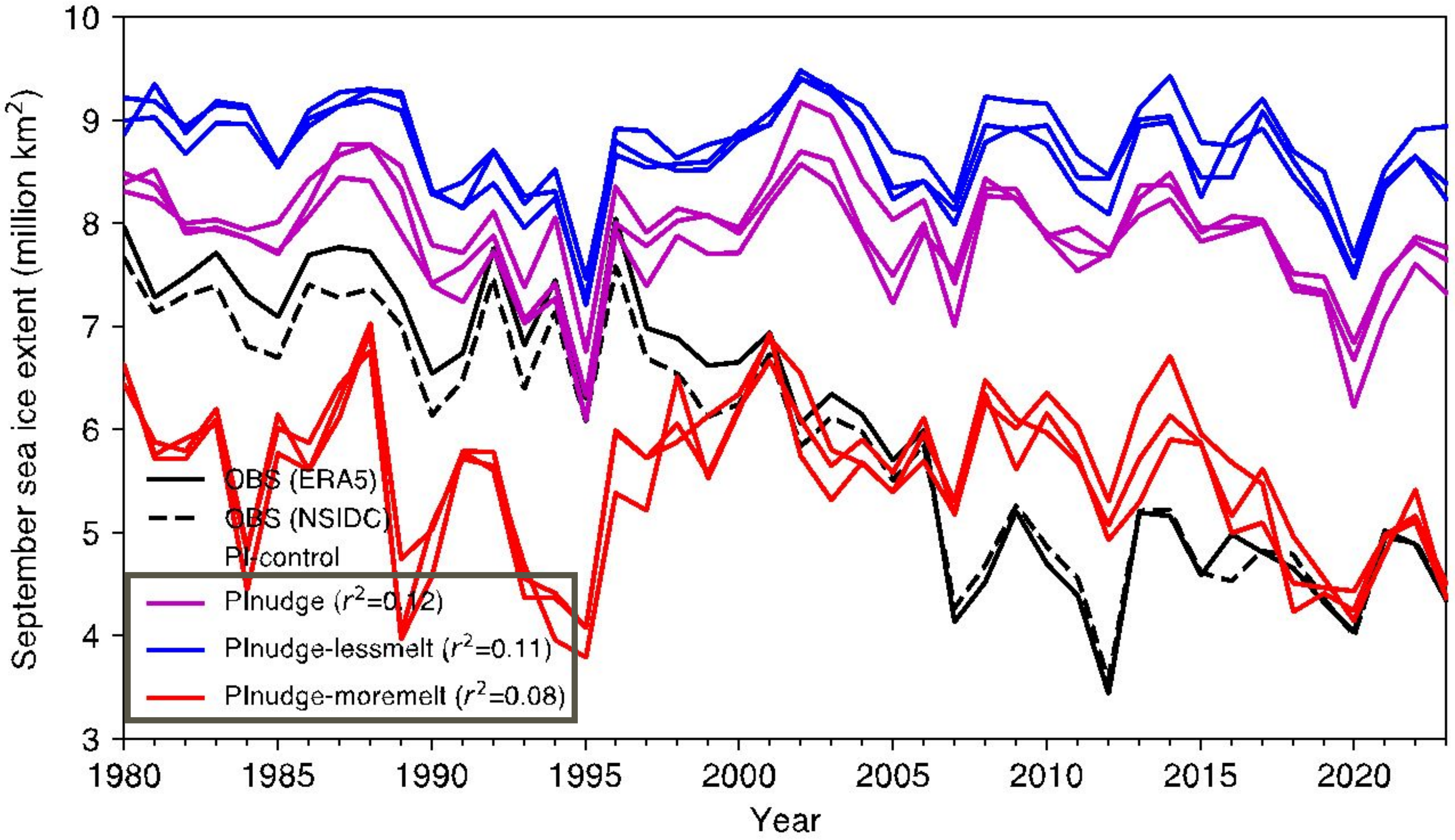
0.11 K/decade

0.12 K/decade

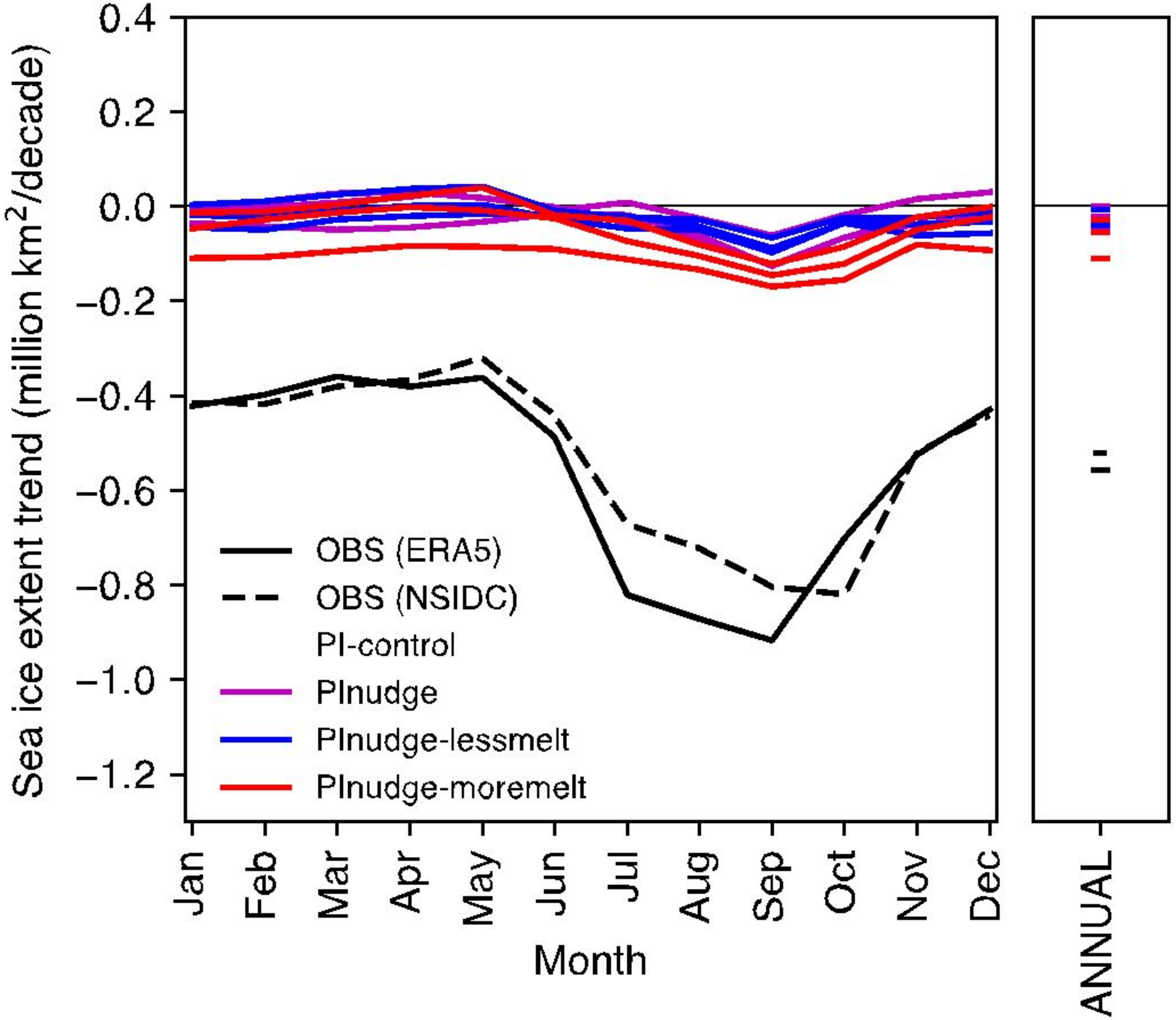
0.14 K/decade

16-20% annual warming

September sea ice extent



Sea ice extent trends

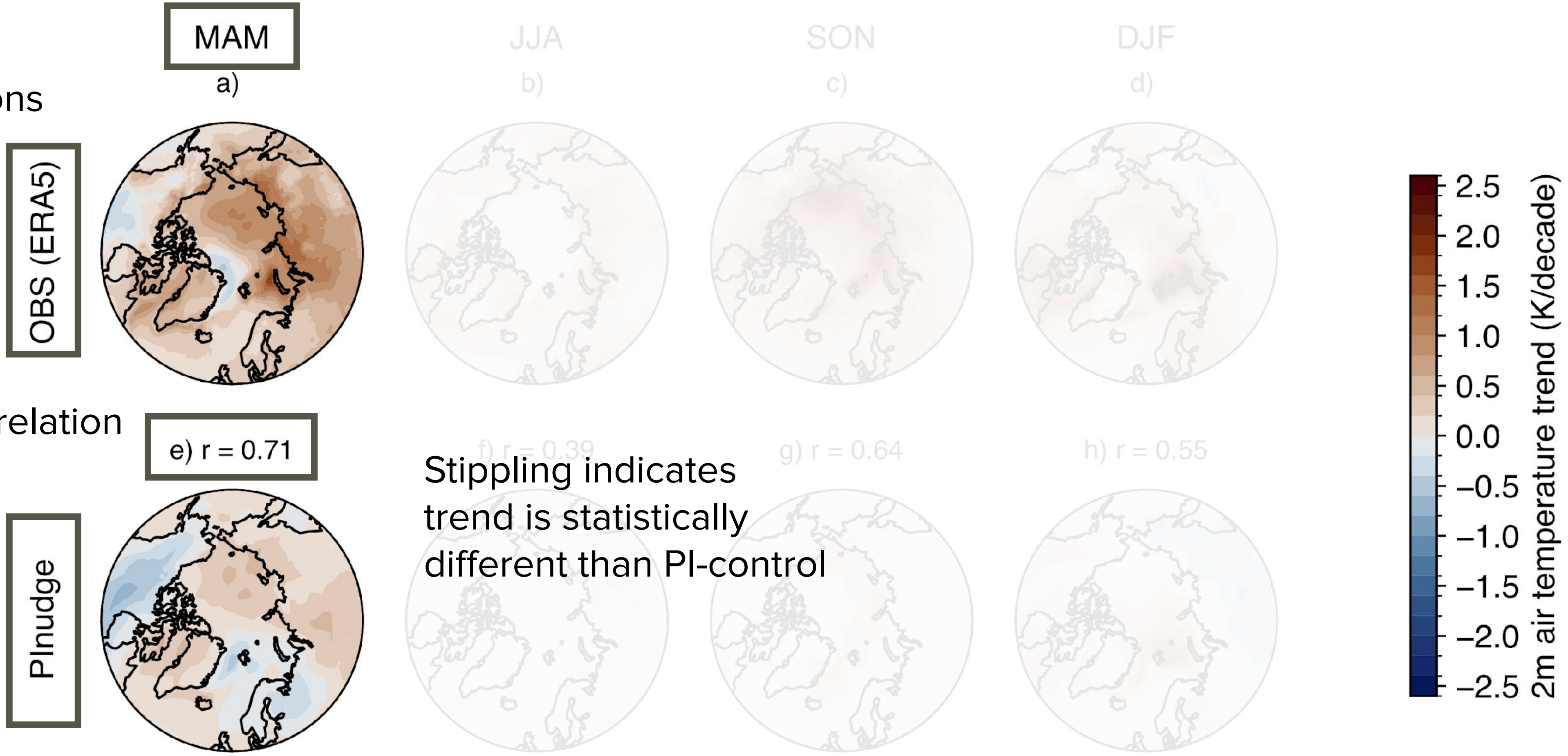


September	March
-0.09 million km^2/decade	-0.01 million km^2/decade
-0.10 million km^2/decade	-0.01 million km^2/decade
-0.15 million km^2/decade	-0.03 million km^2/decade
-0.92 million km^2/decade	-0.36 million km^2/decade
10-16% Sept. sea ice loss	1-8% Mar. sea ice loss

Season

Observations

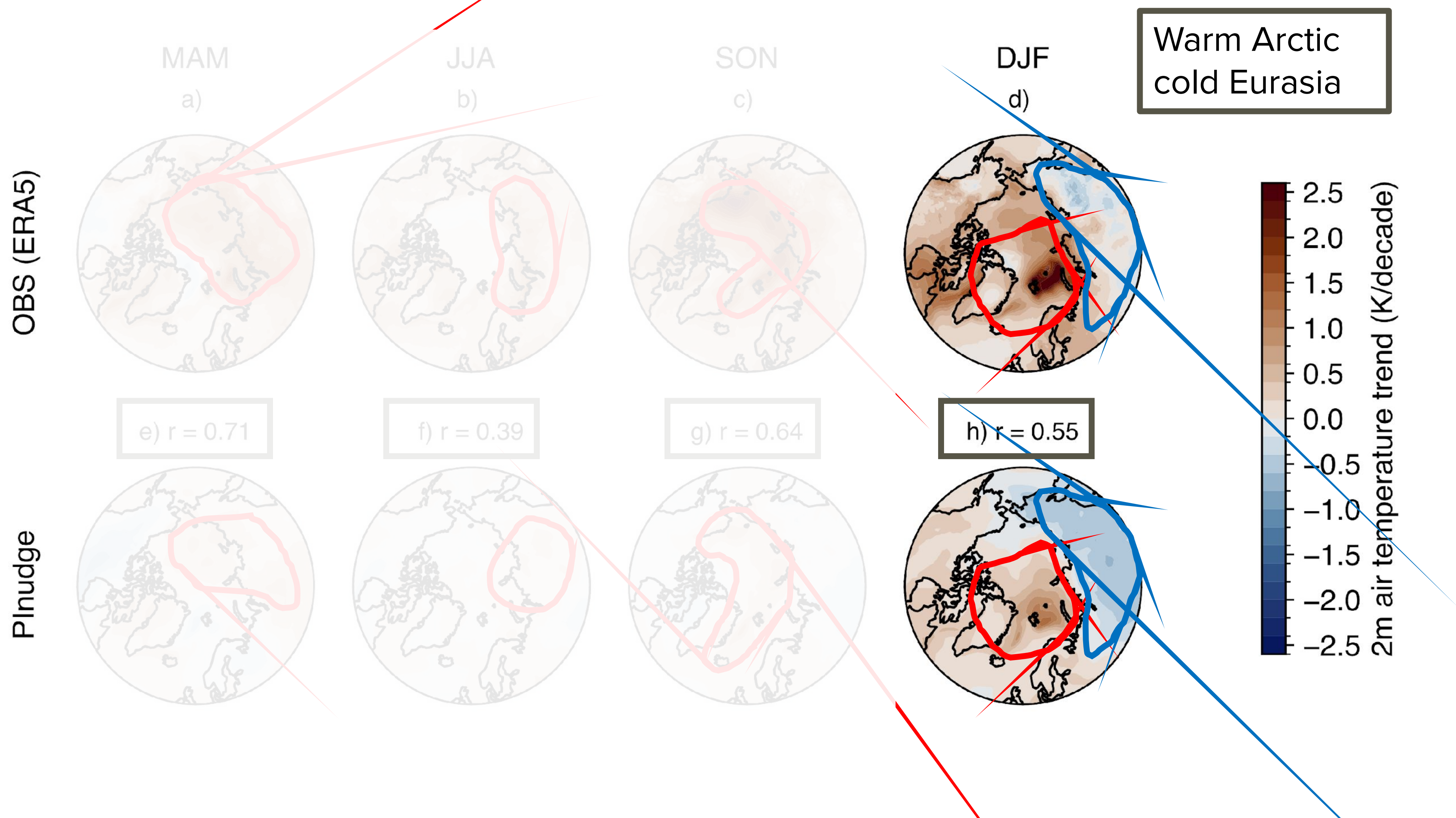
Pattern correlation
with OBS

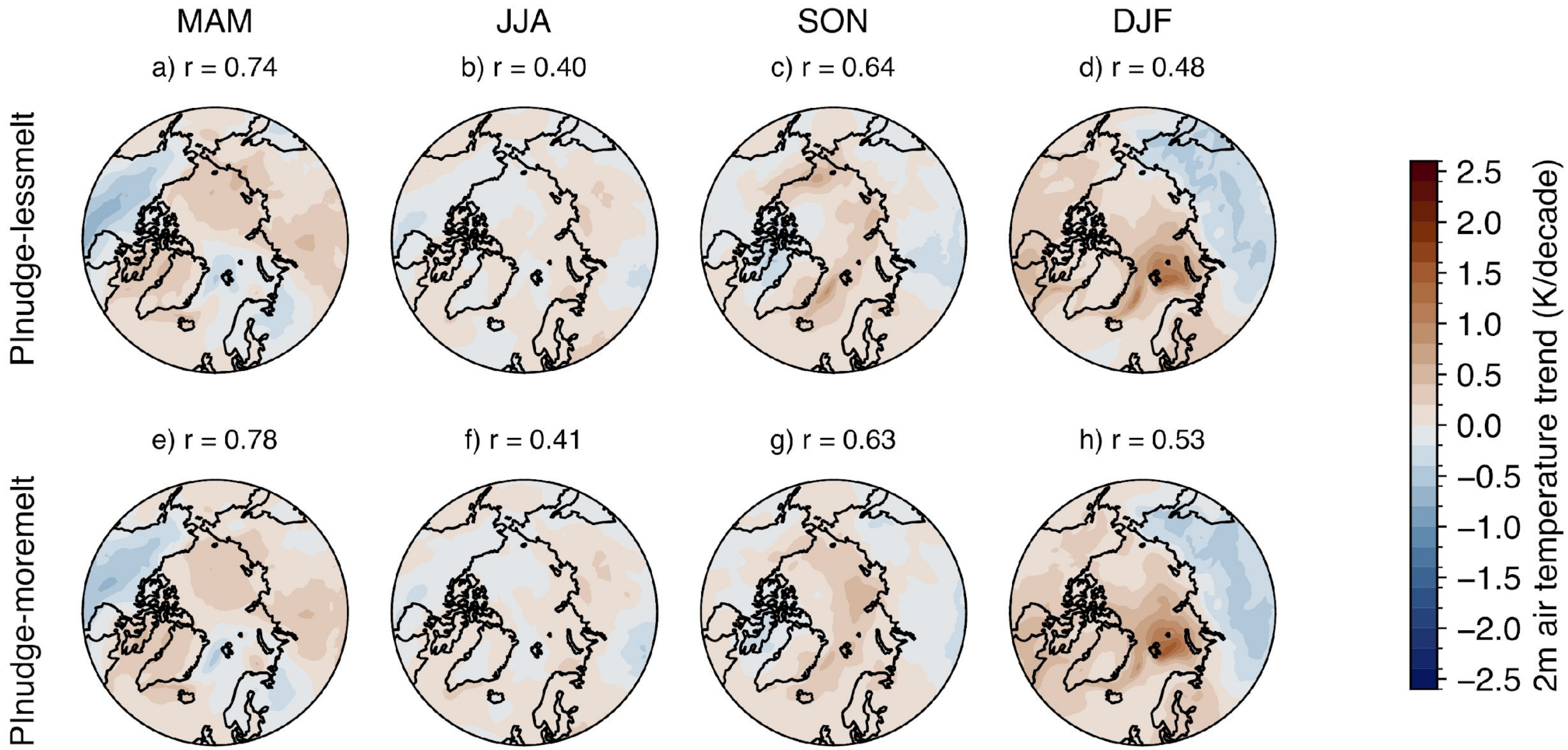


Stippling indicates
trend is statistically
different than PI-control

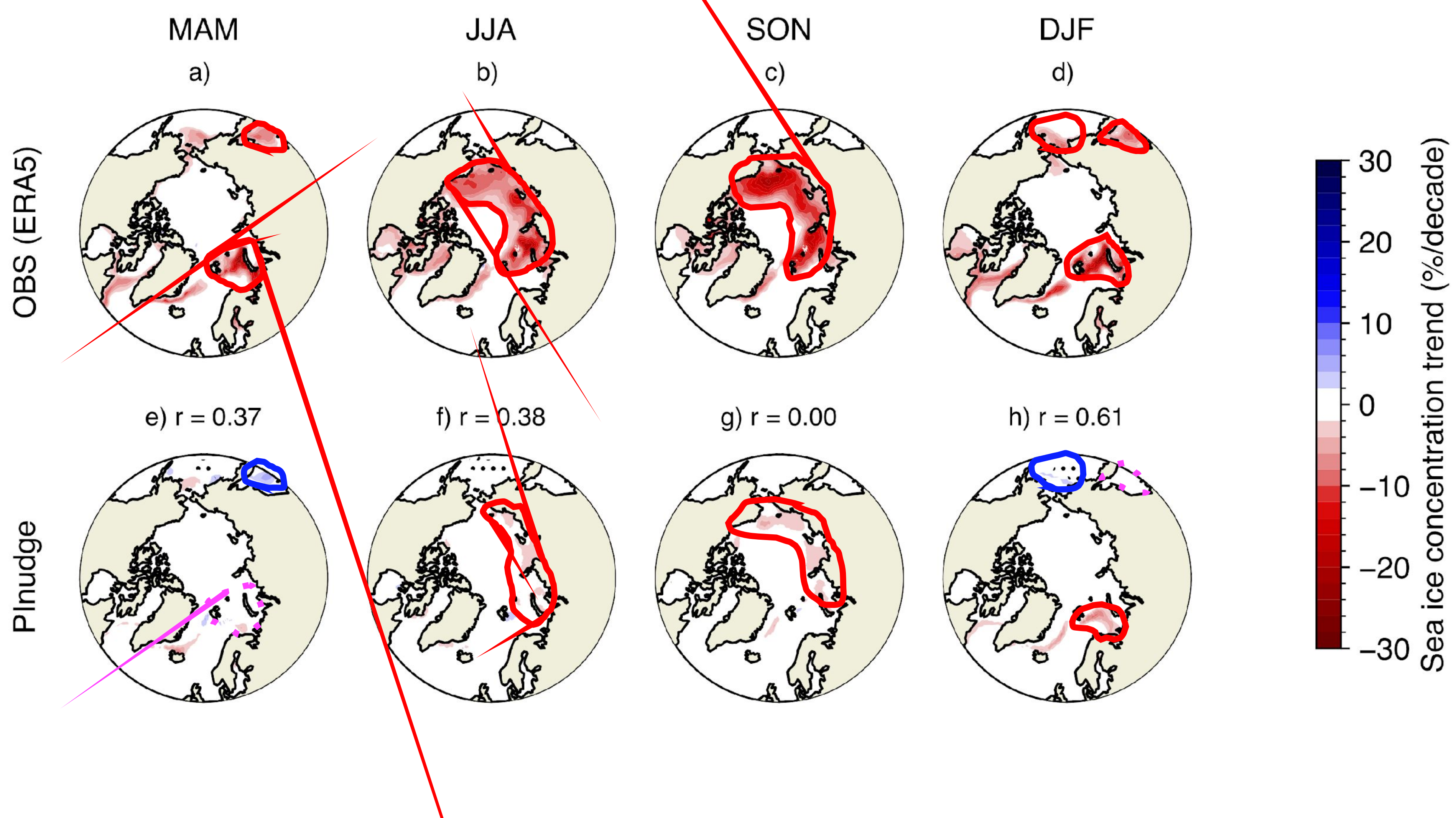
Wind-nudged
experiment

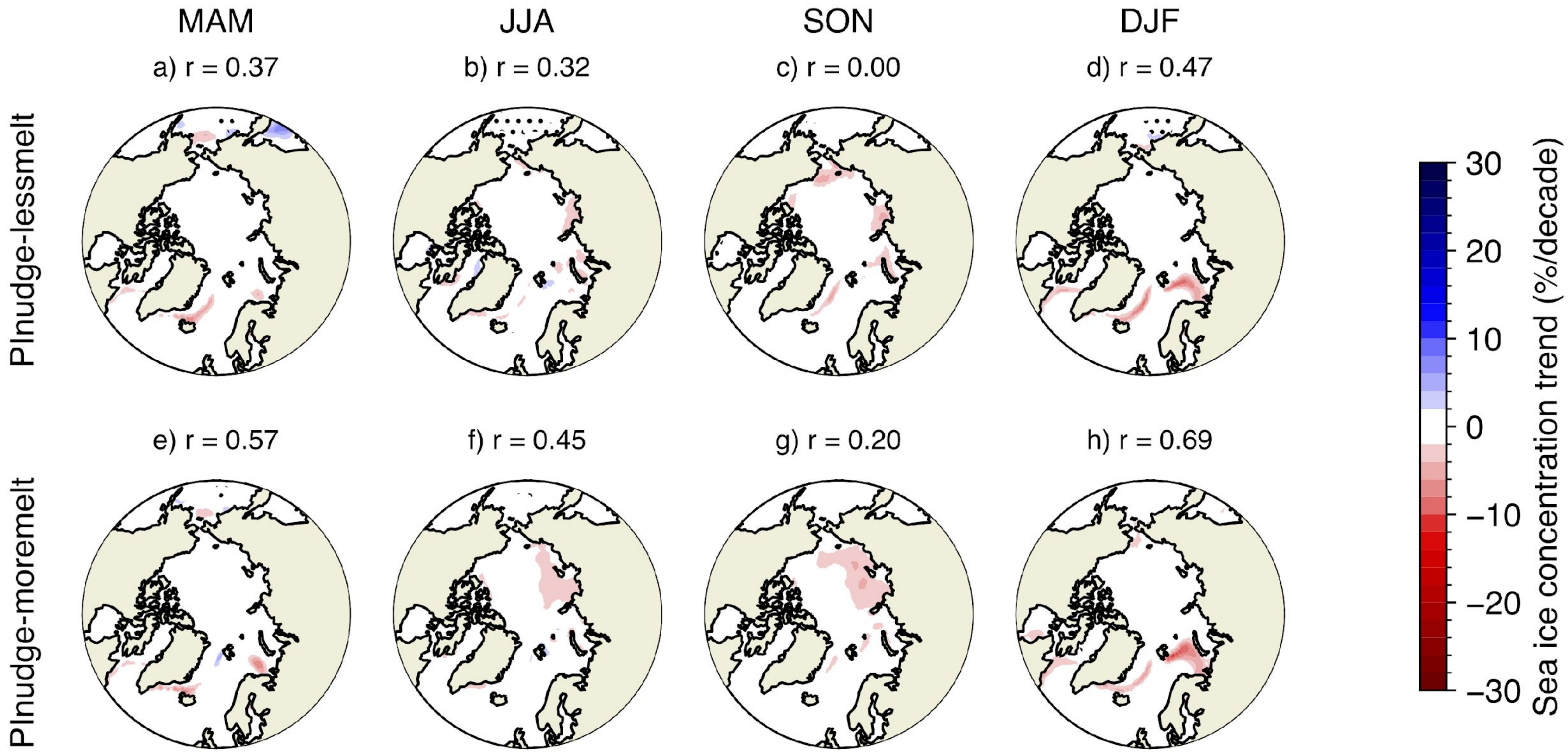
Winds drive location of strongest warming in every season




MAM
JJA
SON
DJF
a) r = 0.74
b) r = 0.40
c) r = 0.64
d) r = 0.48
PInudge-lessmelt
e) r = 0.78
f) r = 0.41
g) r = 0.63
h) r = 0.53
PInudge-moremelt
2.5
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0
−2.5
2m air temperature trend (K/decade)

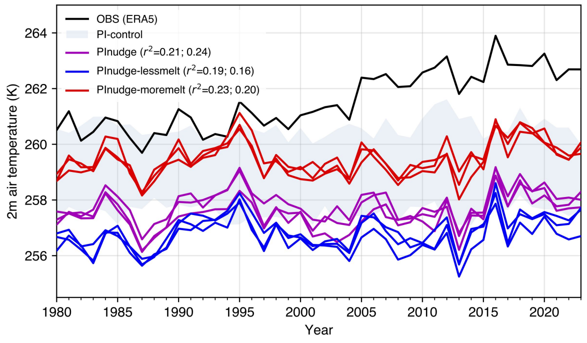
Winds seasonally drive location of strongest sea ice loss

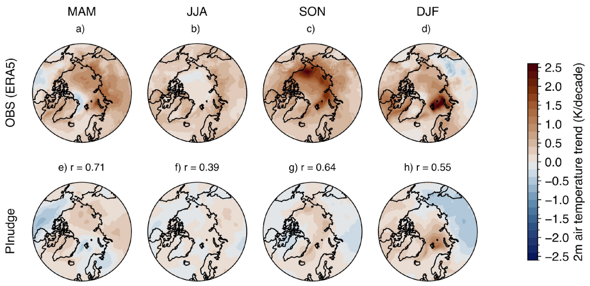



MAM
JJA
SON
DJF
a) r = 0.37
b) r = 0.32
c) r = 0.00
d) r = 0.47
PInudge-lessmelt
e) r = 0.57
f) r = 0.45
g) r = 0.20
h) r = 0.69
PInudge-moremelt
30
20
10
0
−10
−20
−30
Sea ice concentration trend (%/decade)

Conclusions

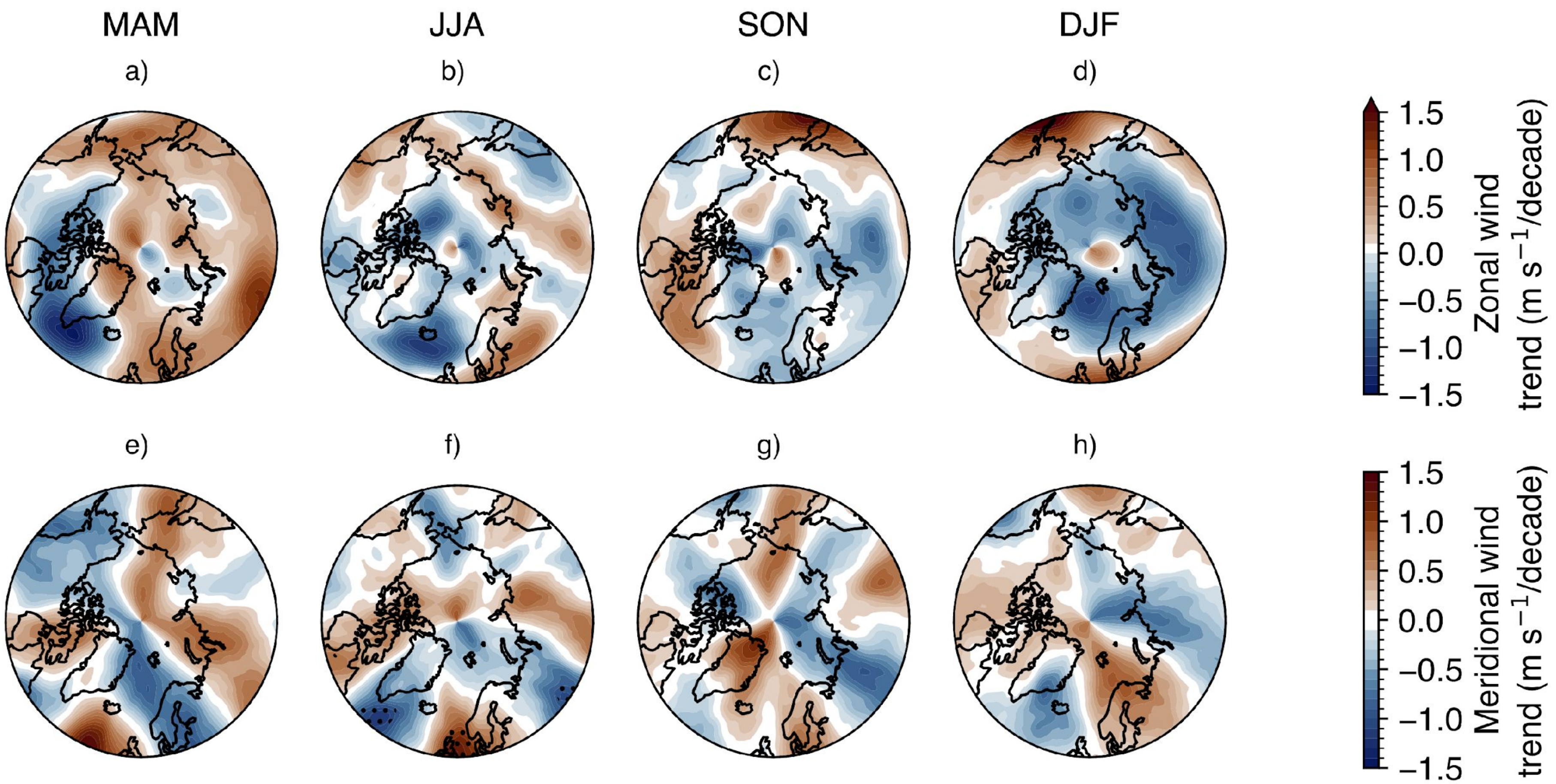
- Observed winds fail to reproduce the magnitude of recent (1980-2023) Arctic warming & sea ice loss
- Observed winds partially reproduce the interannual, seasonal, and spatial variability of Arctic temperature & sea ice
- In summary, observed winds drive Arctic variability but not long term trends
- Our results are independent of mean state sea ice thickness



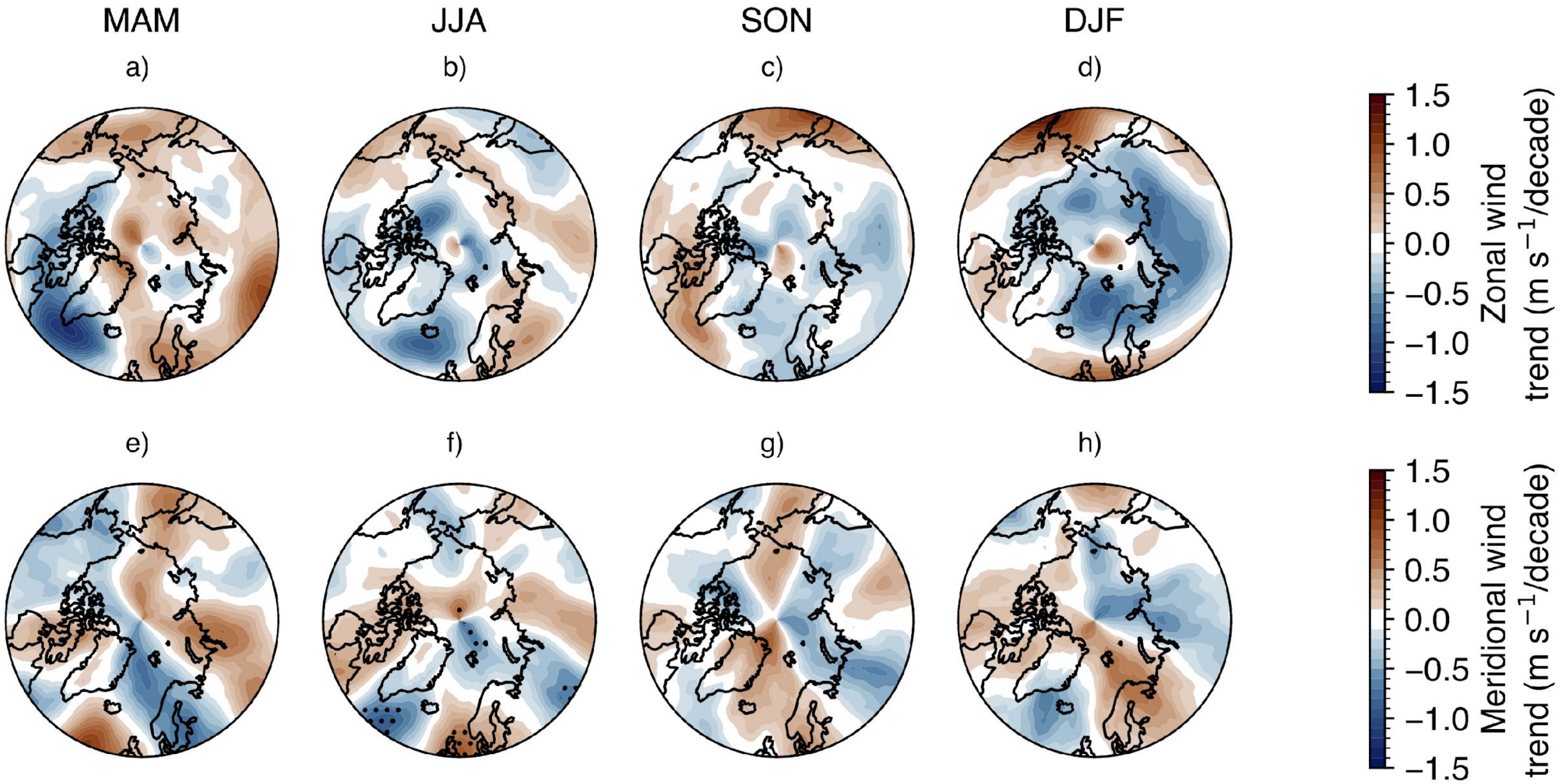


Contact info: ash.gilbert@colorado.edu

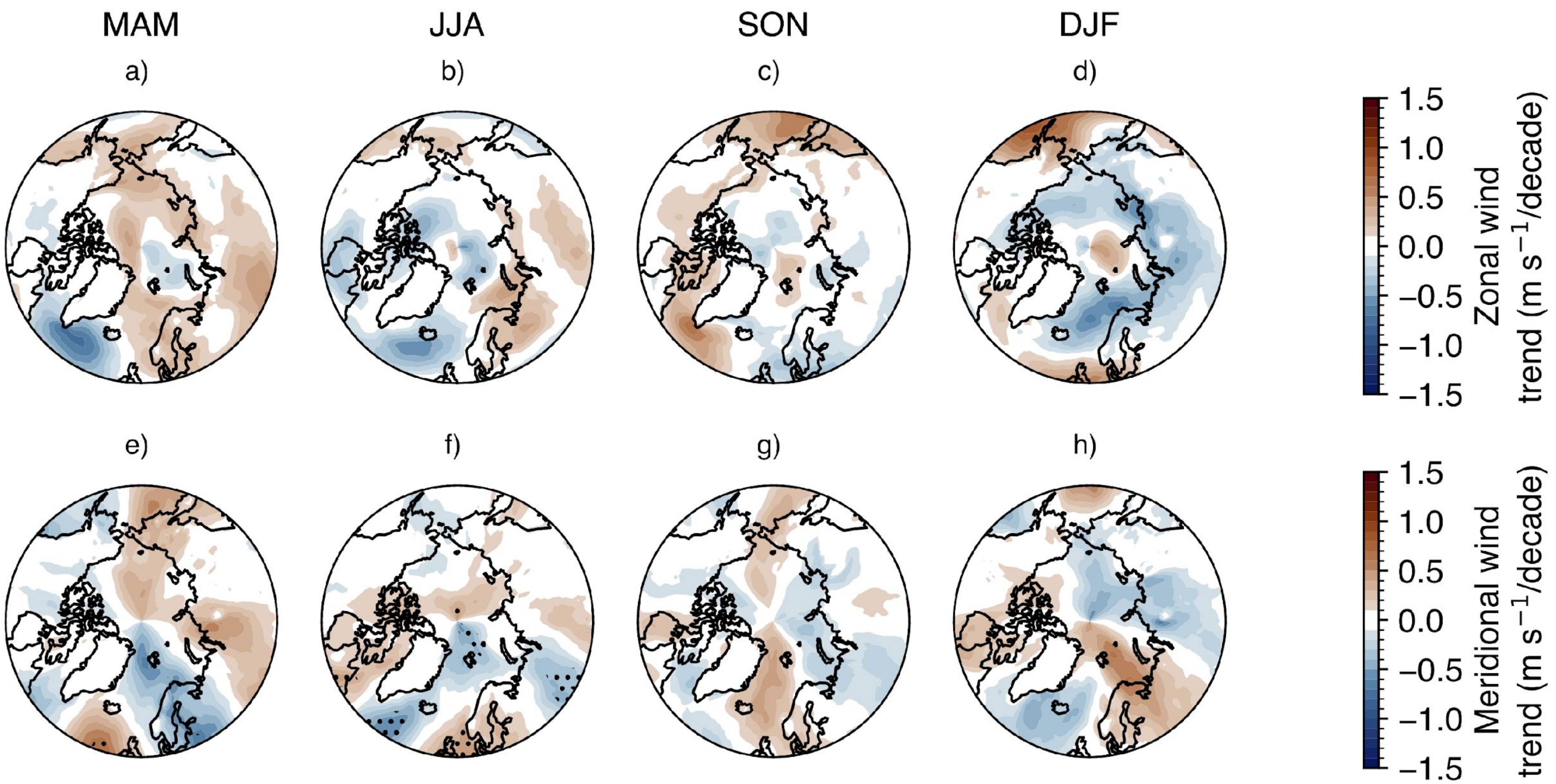
300 hPa


MAM
JJA
SON
DJF
a)
b)
c)
d)
e)
f)
g)
h)
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
Zonal wind trend (m s−1/decade)
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
Meridional wind trend (m s−1/decade)

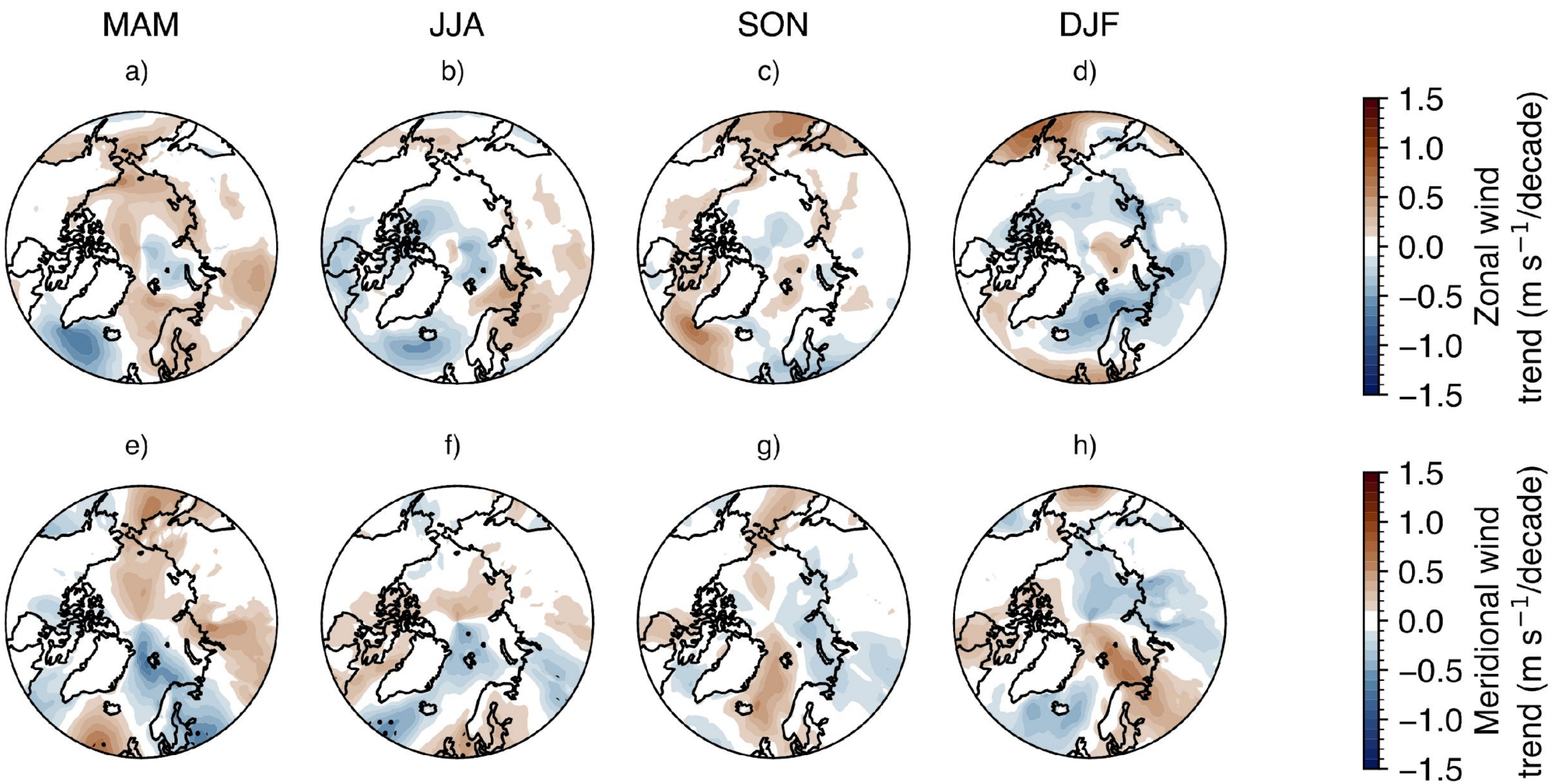
500 hPa

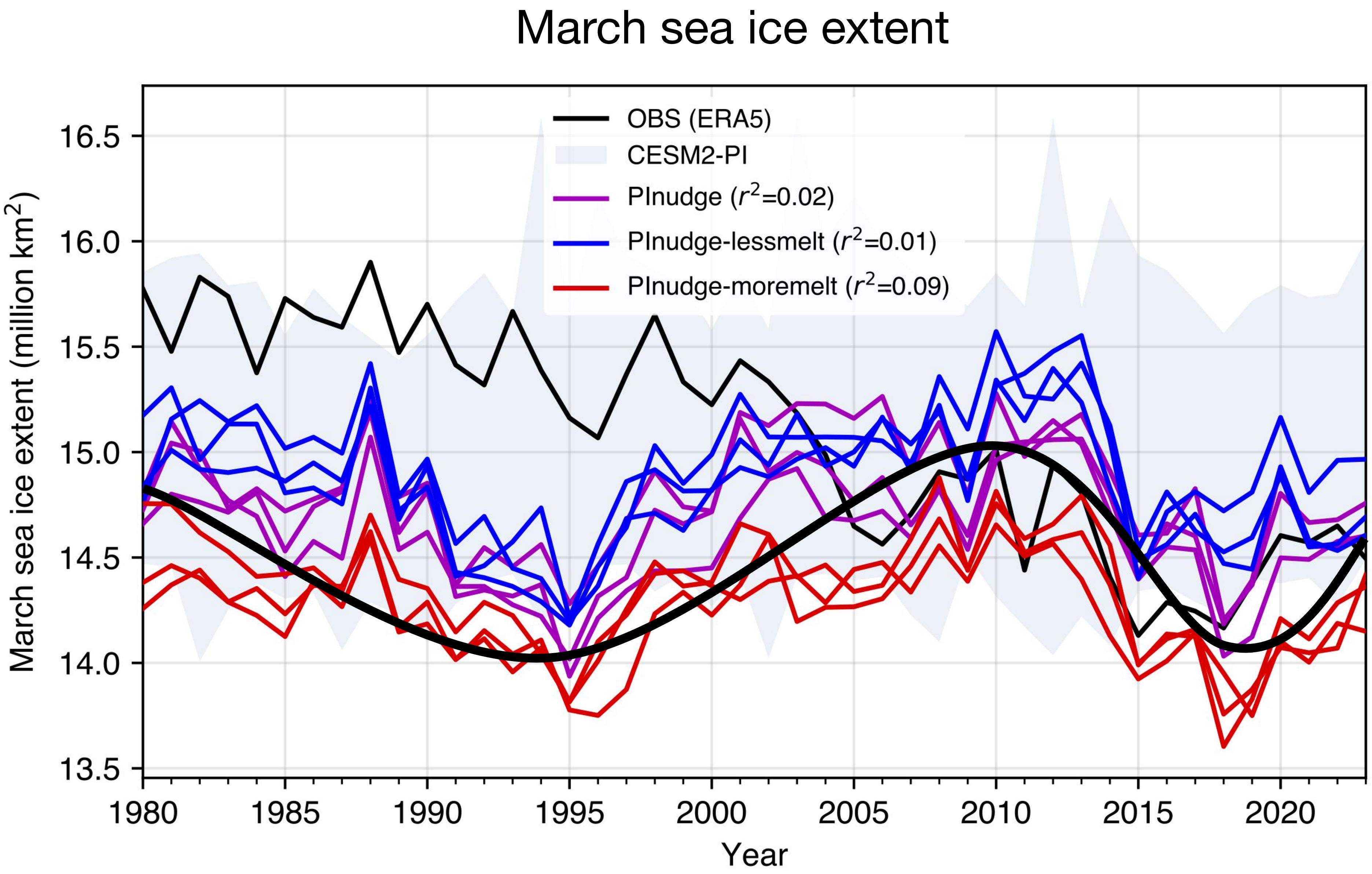

MAM
JJA
SON
DJF
a)
b)
c)
d)
e)
f)
g)
h)
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
Zonal wind
trend (m s^{-1}/decade)
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
Meridional wind
trend (m s^{-1}/decade)

850 hPa

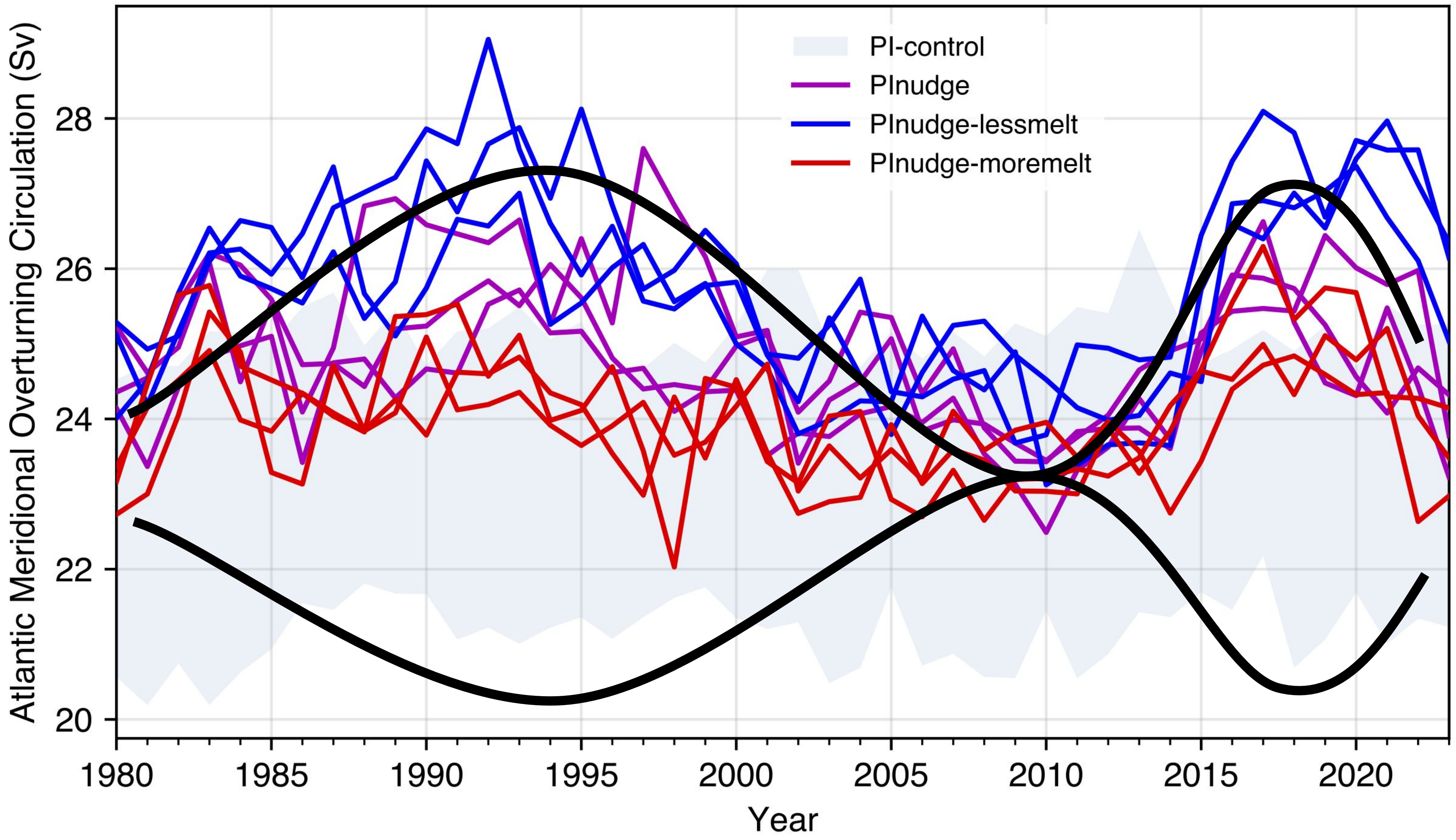

MAM
JJA
SON
DJF
a)
b)
c)
d)
e)
f)
g)
h)
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
Zonal wind trend (m s^{-1}/decade)
Meridional wind trend (m s^{-1}/decade)

925 hPa


MAM
JJA
SON
DJF
a)
b)
c)
d)
e)
f)
g)
h)
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
Zonal wind trend (m s^{-1}/decade)
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
Meridional wind trend (m s^{-1}/decade)

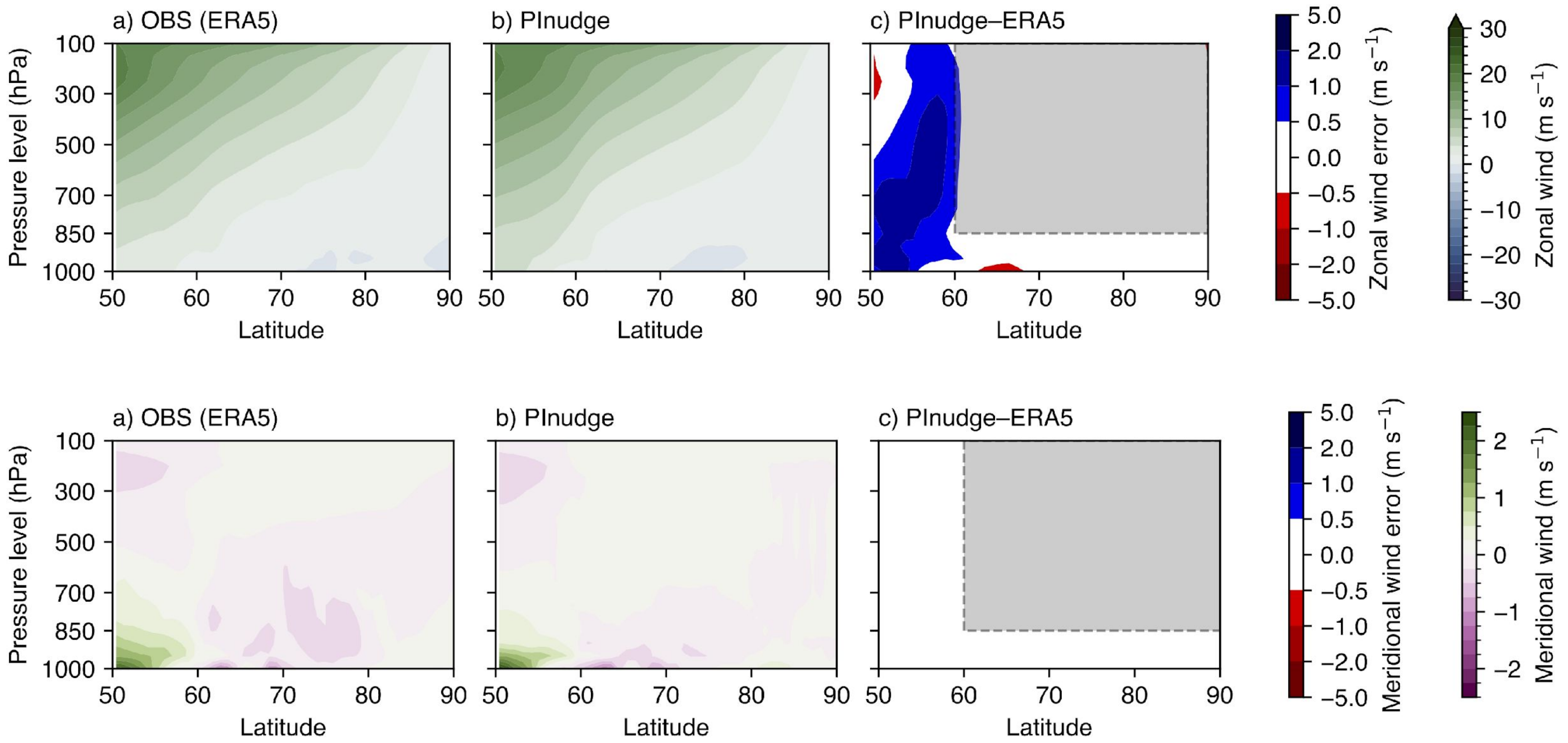

March sea ice extent
OBS (ERA5)
CESM2-PI
PInudge (r^2=0.02)
PInudge-lessmelt (r^2=0.01)
PInudge-moremelt (r^2=0.09)
March sea ice extent (million km^2)
16.5
16.0
15.5
15.0
14.5
14.0
13.5
1980
1985
1990
1995
2000
2005
2010
2015
2020
Year

Atlantic Meridional Overturning Circulation (AMOC)



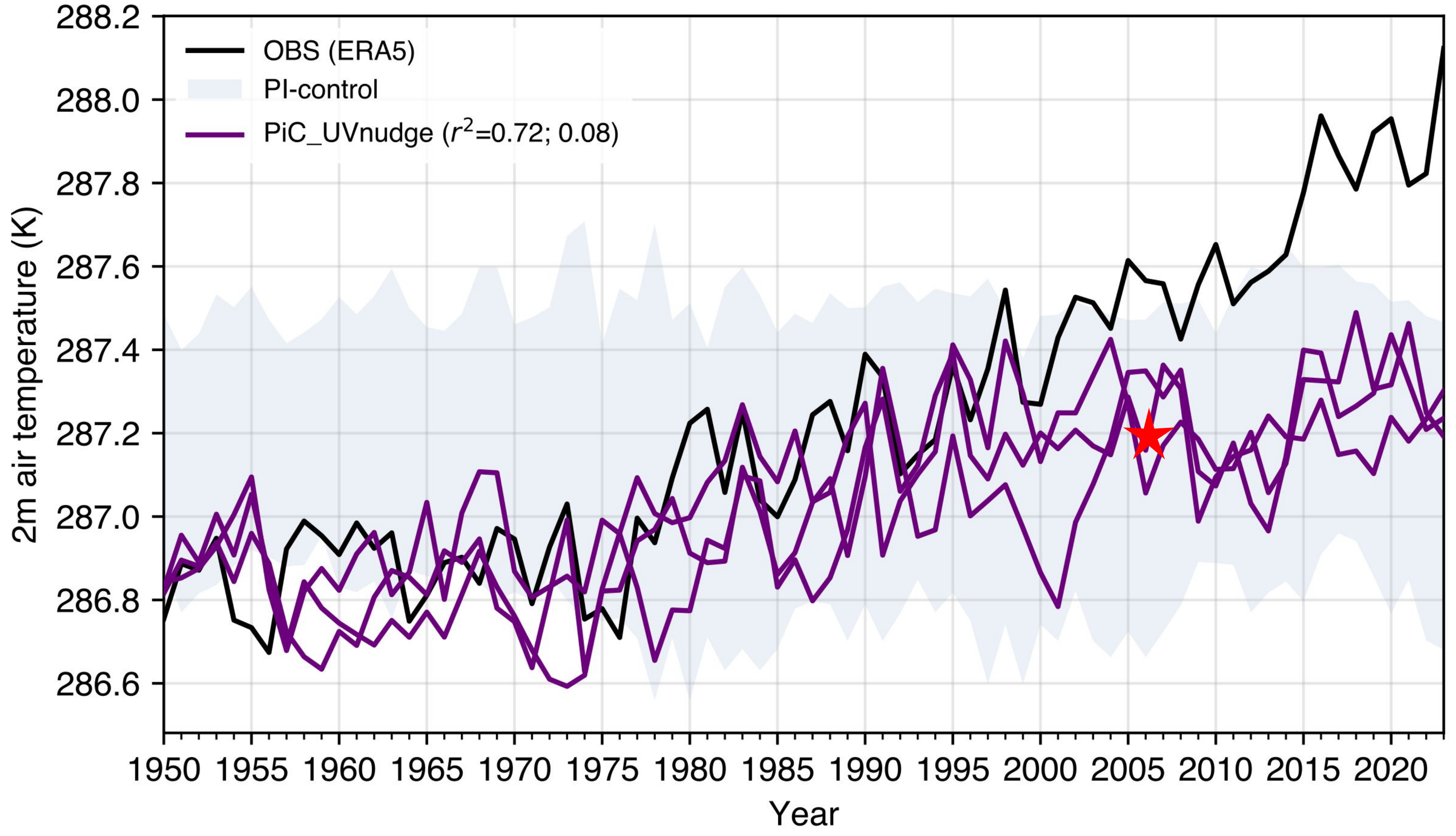
March sea ice oscillation

Wind nudging in practice…

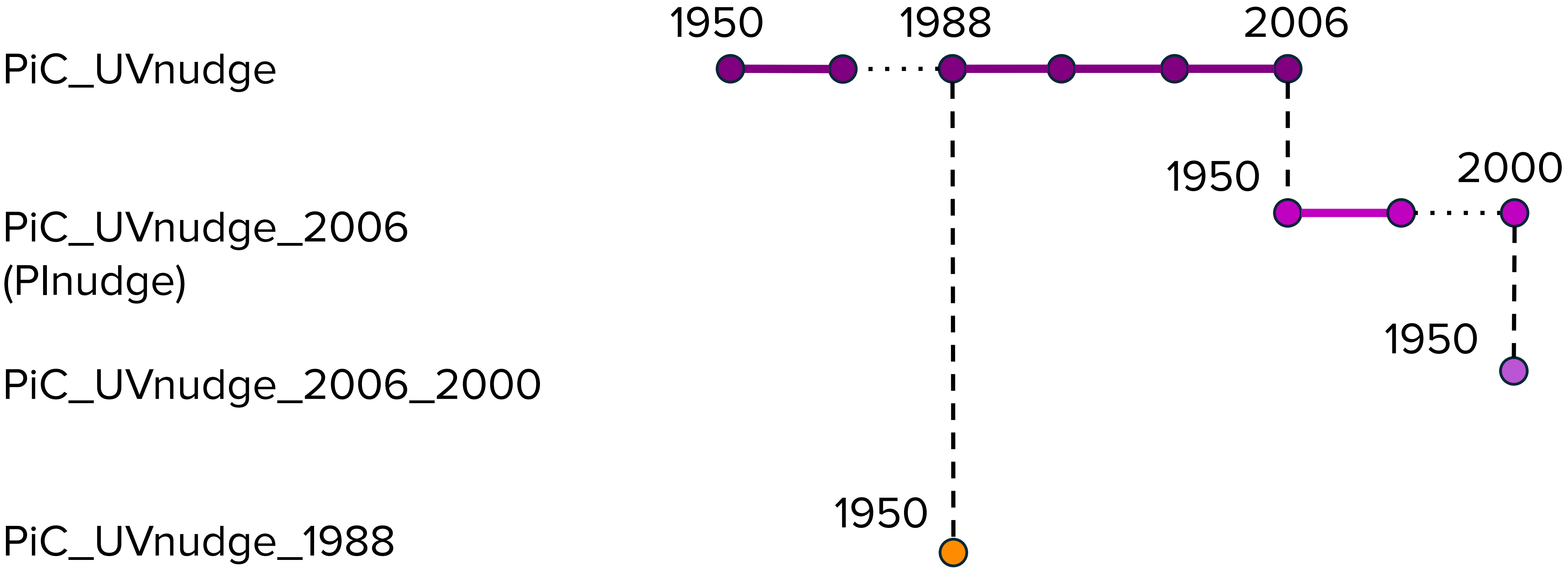


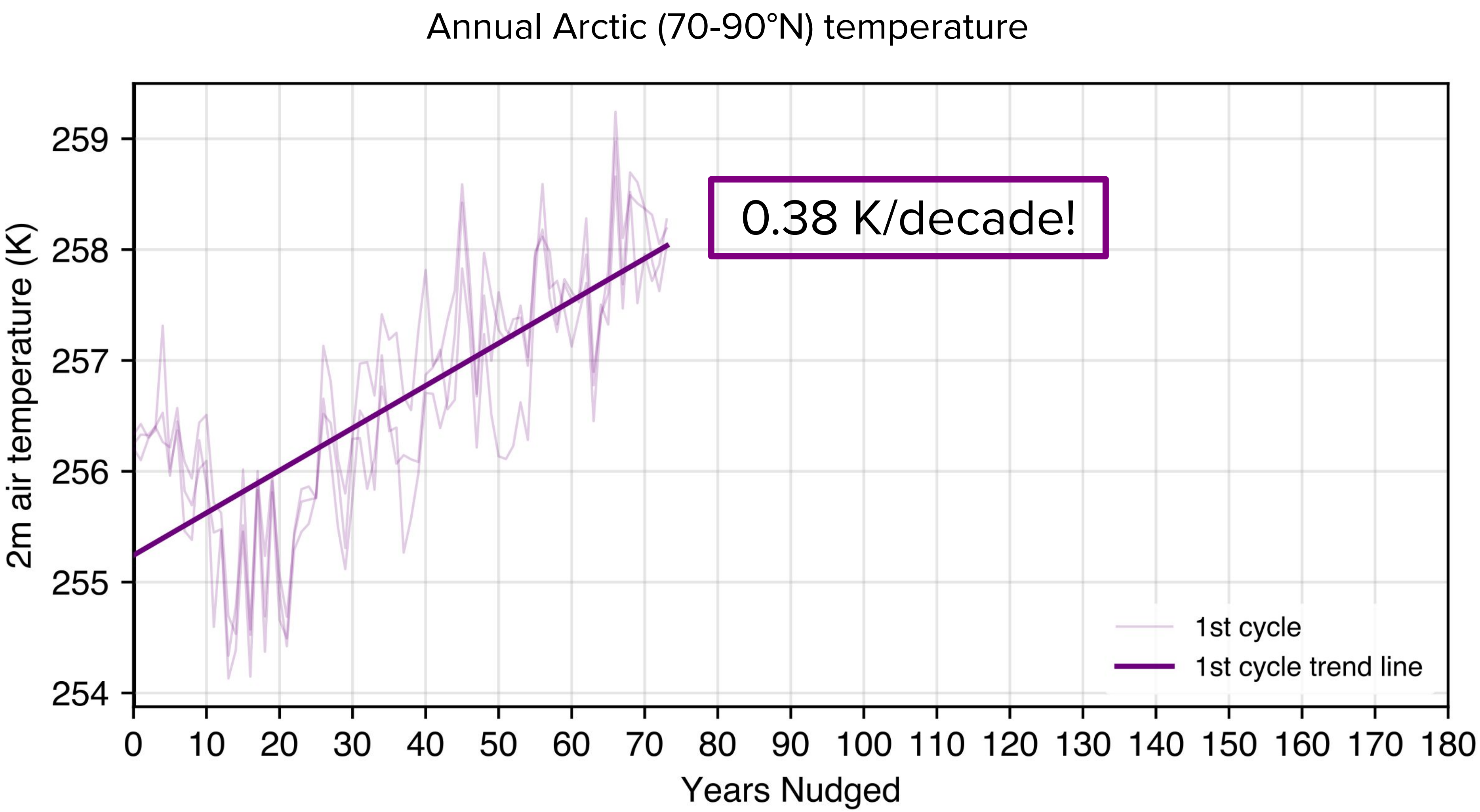
Experiment name	Initial condition	Physics/Namelist changes	Ensemble members	Experiment type
PiC_UVnudge	Year 501 of PI-control		3	Spin-up
PiC_UVnudge_LM	Year 1181 of PI-lessmelt	Lessmelt CICE mods	3	Spin-up
PiC_UVnudge_MM	Year 1181 of PI-moremelt	Moremelt CICE mods	3	Spin-up
PiC_UVnudge_2006 (i.e. PInudge)	Year 2006 of PiC_UVnudge		3	Science
PiC_UVnudge_LM2006 (i.e. PInudge-lessmelt)	Year 2006 of PiC_UVnudge_LM	Lessmelt CICE mods	3	Science
PiC_UVnudge_MM2006 (i.e. PInudge-moremelt)	Year 2006 of PiC_UVnudge_MM	Moremelt CICE mods	3	Science
PiC_UVnudgenew	Year 501 of CESM2 piControl	New nudging physics	1	Drift
PiC_UVnudge_1988	Year 1988 of PiC_UVnudge mem. 3		1	Drift
PiC_UVnudge_2006_2000	Year 2000 of PiC_UVnudge_2006 mem. 1		1	Drift

Global mean temperature



Full initial condition tree





Observed trend:
0.4-0.5 K/decade

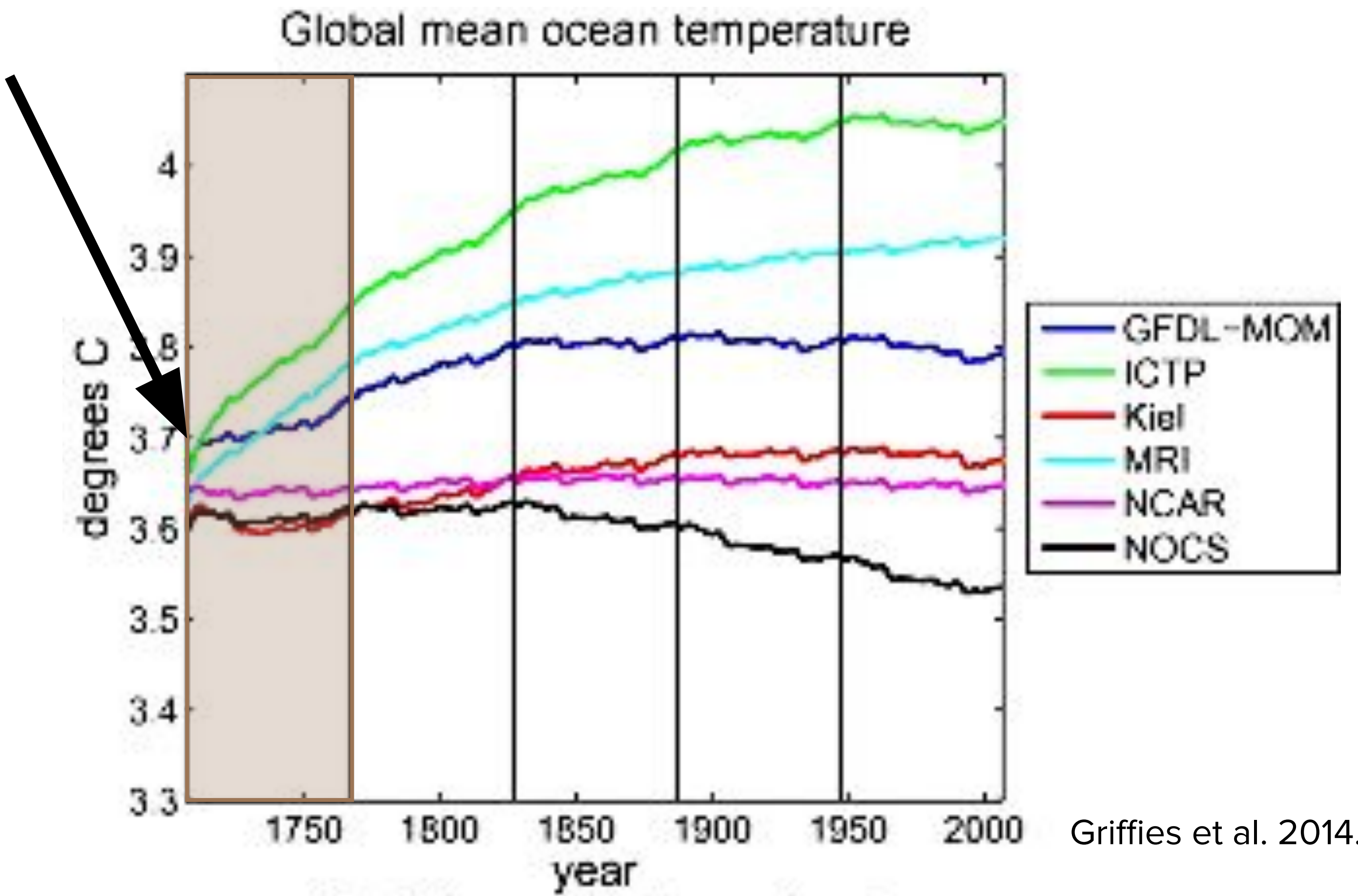
Drift

or

Signal

Cycling atmospheric forcing in ocean models removes model drift

Each box is one cycle of atmospheric forcing



Griffies et al. 2014.

Drift: cycling wind nudging reduces the temperature trend

Signal: cycling wind nudging has no effect on the temperature trend

0.12 K/decade

0.16 K/decade

Drift

or

Signal

Drift removed & 2nd cycle can be used for science!

PInudge = 2nd cycle
PInudge-lessmelt = 2nd cycle
PInudge-moremelt = 2nd cycle