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

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0.6 K/decade spread

2.0 Arctic Amplification factor spread

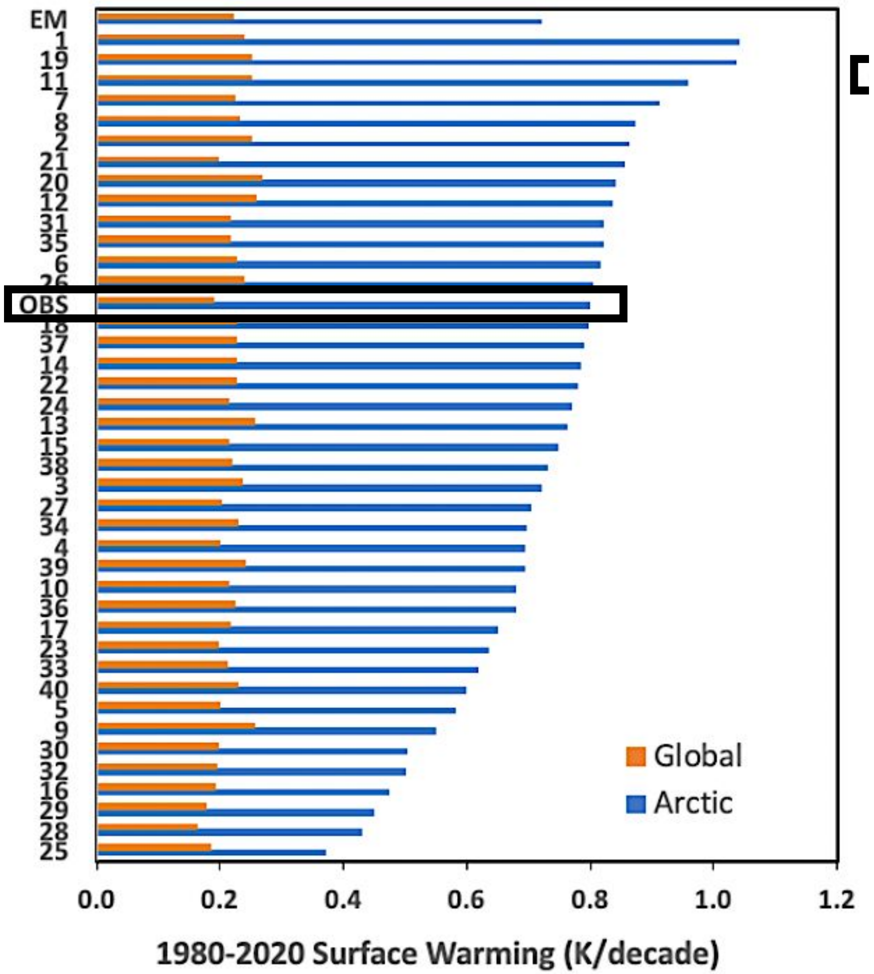


Figure 1. Arctic (70-90 °N) and Global warming (left) and Arctic Amplification (right). Values for individual members and ensemble mean (EM) of the CESM1 Large Ensemble (*Kay et al. 2015*) and for observations (*GISTEMP Team, 2021*).

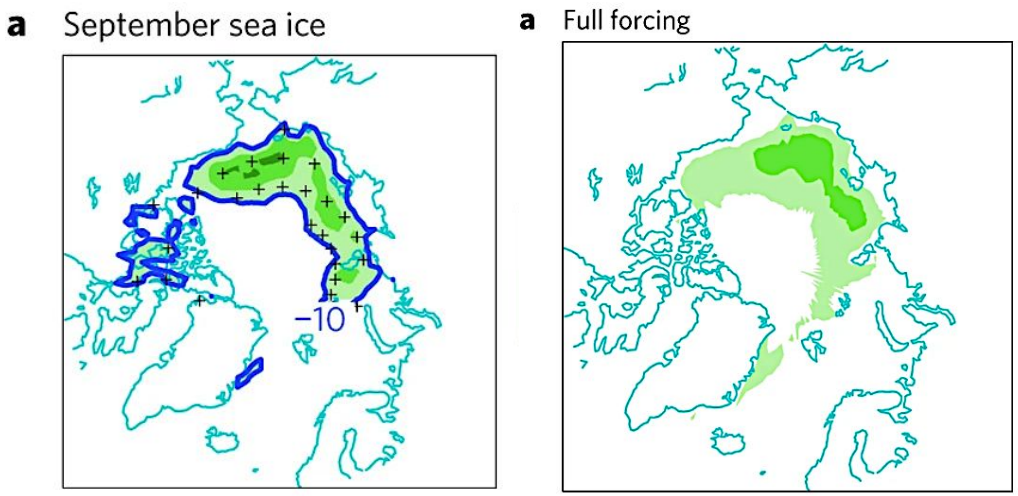
H… the
o… rctic
wa… bility

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

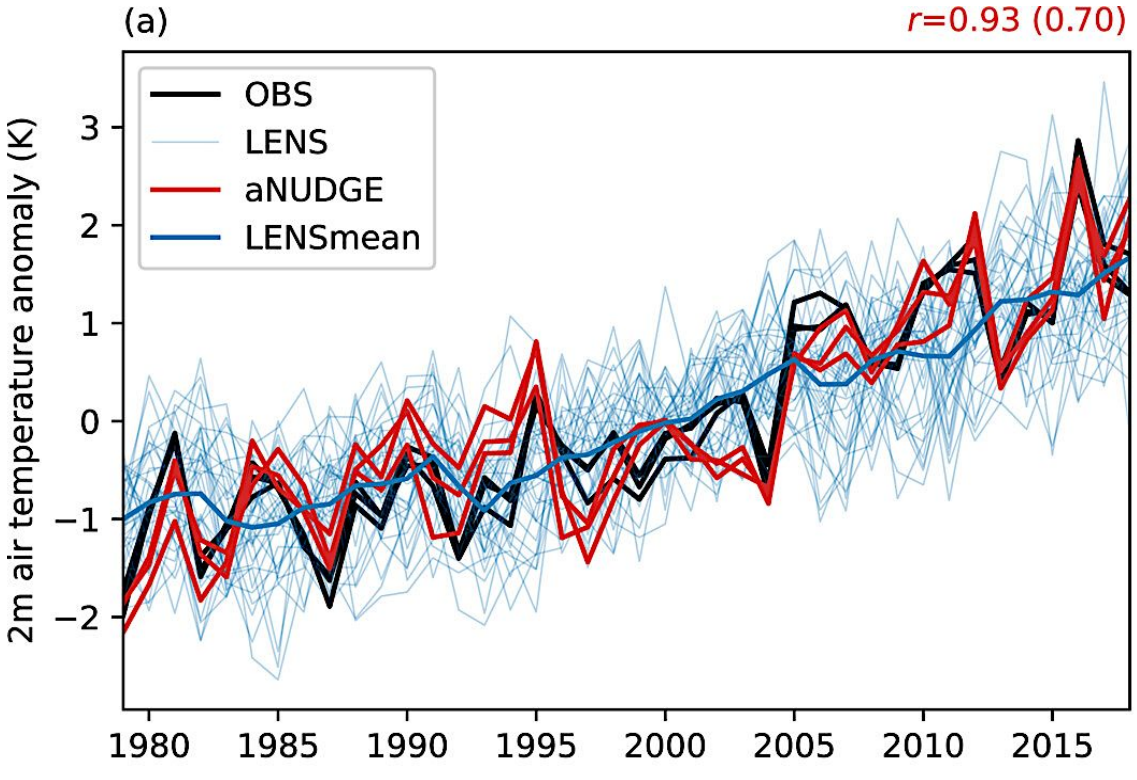
Wind contribution to observed September sea ice loss:
- 60% from summertime circulation
- 20-25% from observed circulation

Observations

Nudged



Ding et al. 2017.



Roach and Blanchard-Wrigglesworth 2022.

All previous work:

Anthropogenic forcing + Observed large-scale winds → Assessment of wind contribution to observed trends

Unknown:

No anthropogenic forcing

Observed large-scale winds → Assessment of wind contribution to observed trends

Research Questions

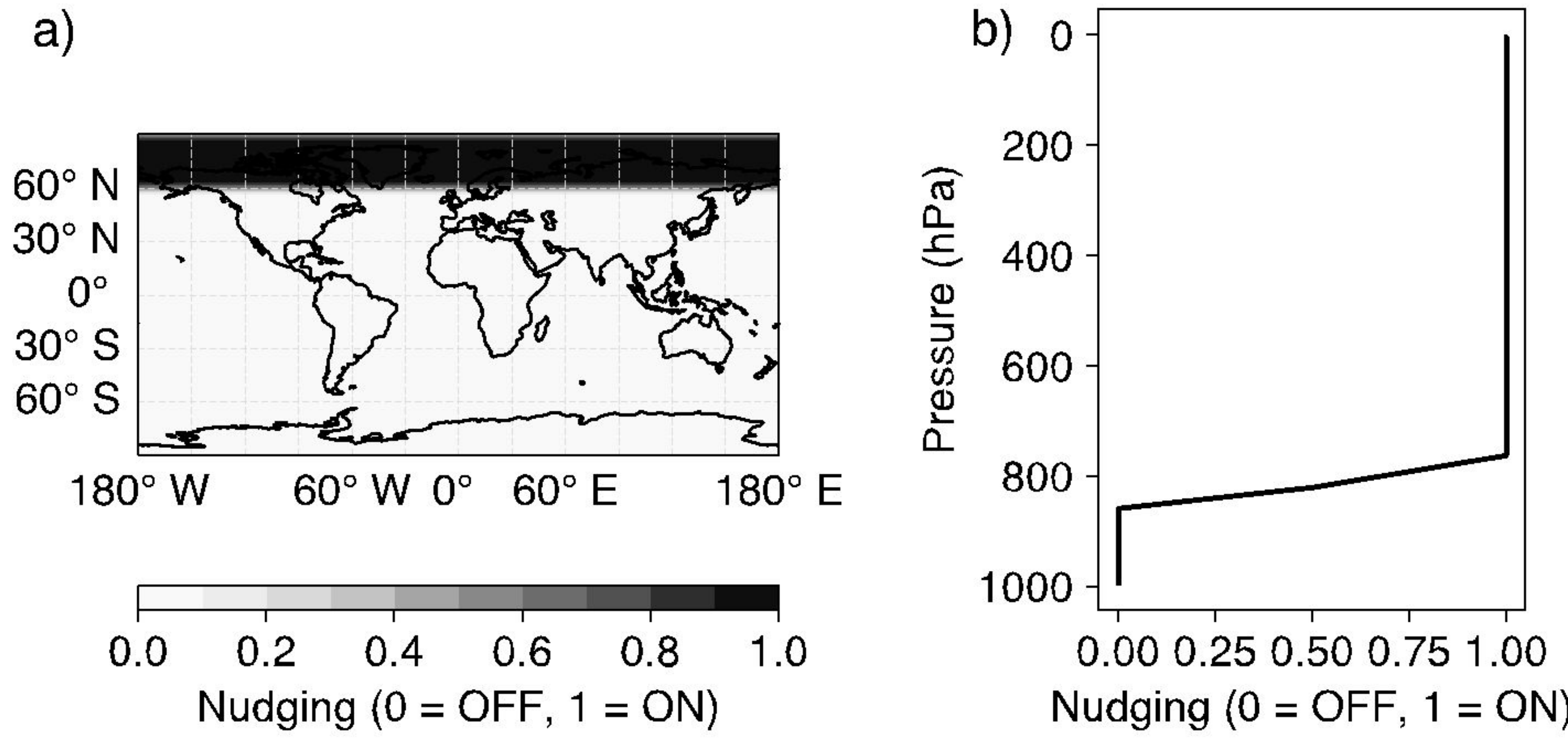
What is the influence of the observed winds alone on:

1) Observed Arctic warming and sea ice loss trends and interannual variability
2) Seasonal temperature and sea ice area trends
3) Local trends in temperature and sea ice

How do those results change for an increase in mean state sea ice thickness?

Experiment set-up

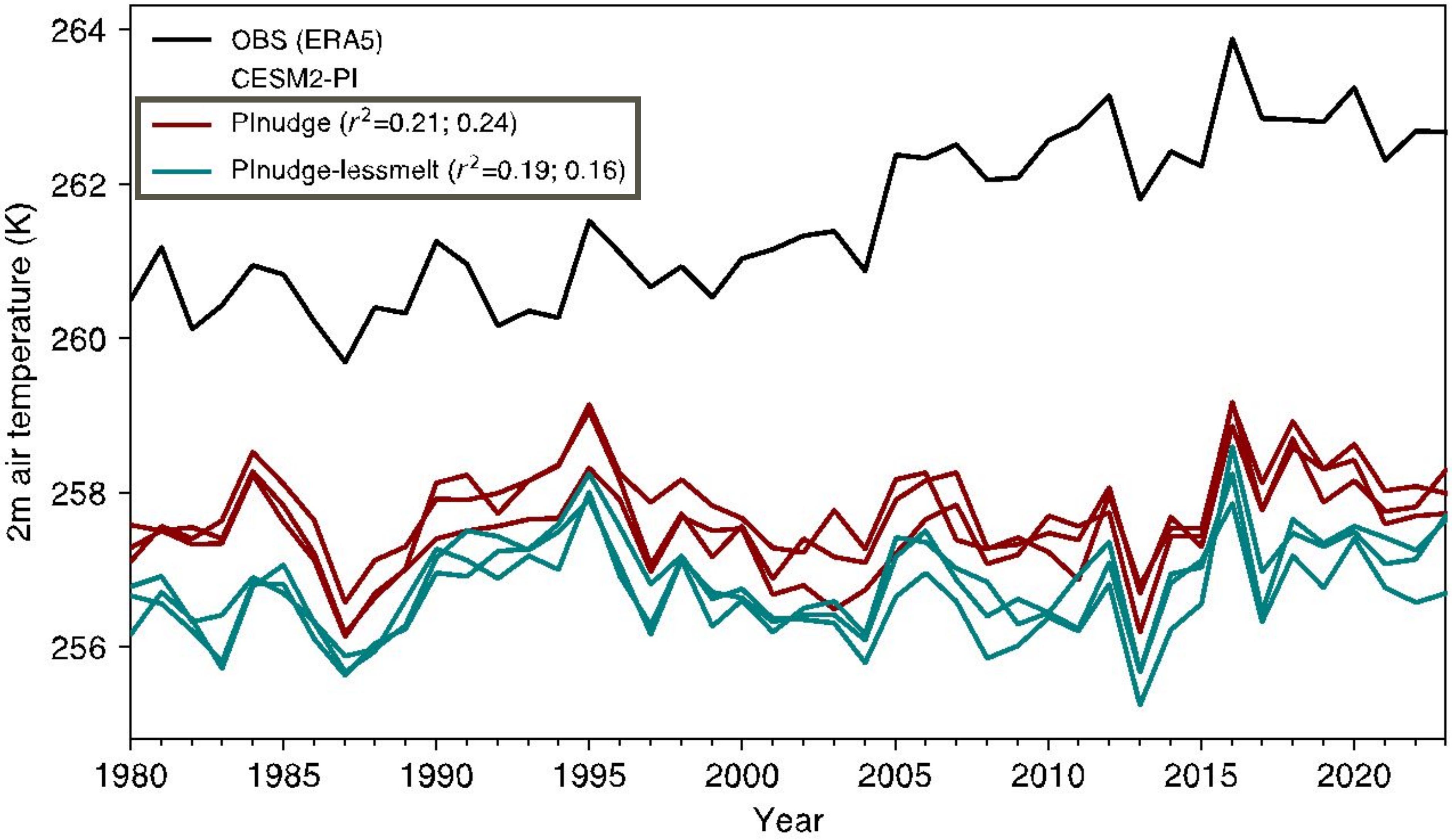
- CESM version 2.1.5
- Pre-industrial climate (B1850cmip6)
- Nudged model U & V wind components with 6-hourly ERA5 reanalysis from 1950-2023 for 60-90°N and above 850 hPa



Dataset name	Ensemble members	Additional notes	Purpose
OBS	–	ERA5 for temperature & sea ice; GISTEMP for temperature anomalies only	Benchmark for performance of wind-nudged experiments
CESM2-PI	51	Ensemble 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

Arctic Temperature Trends & Variability

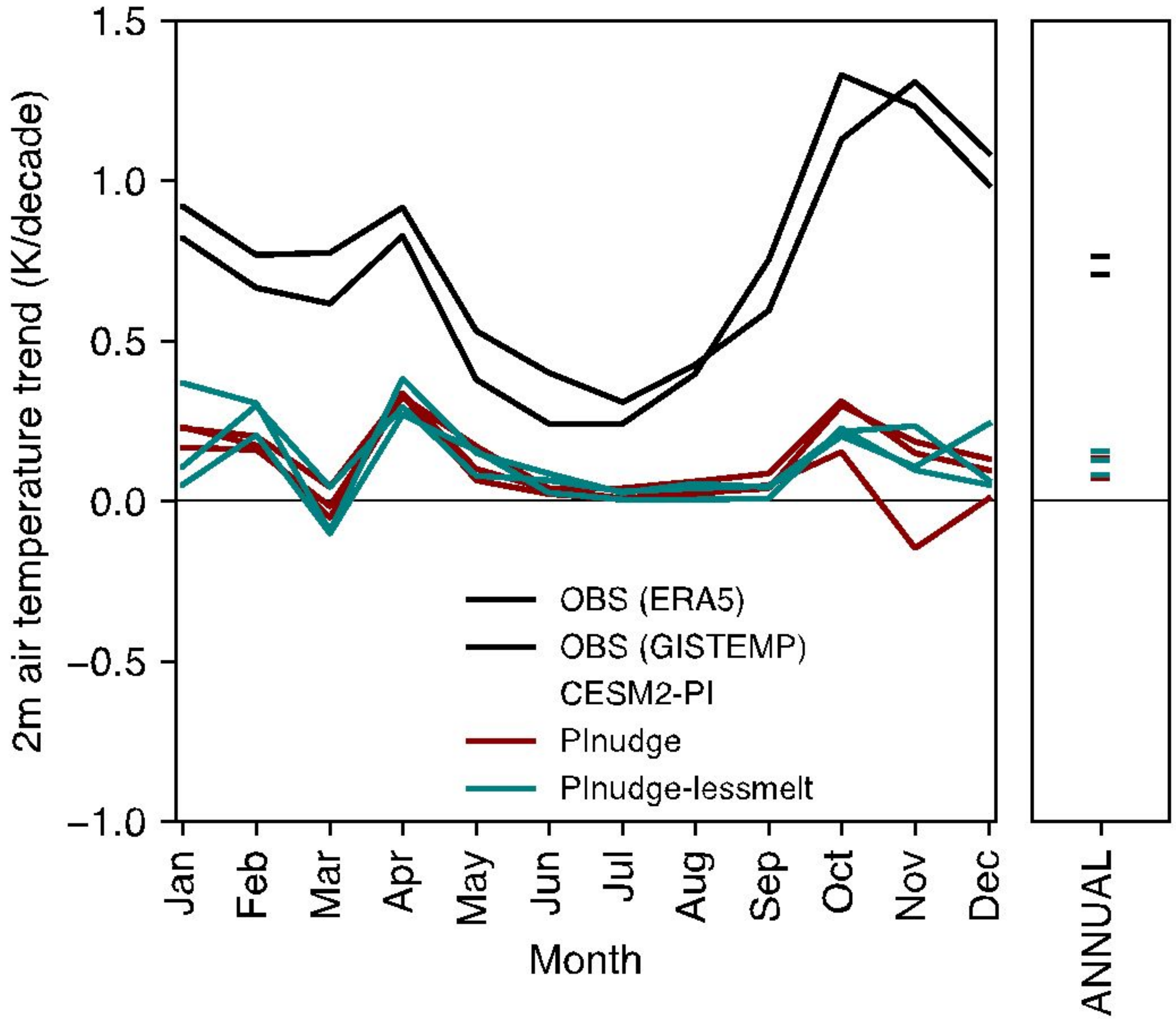
Annual Arctic (70-90°N) temperature



Closer to OBS ➜

Closer to CESM2-PI ➜

Annual Arctic (70-90°N) temperature trends



0.71 K/decade

0.12 K/decade

0.11 K/decade

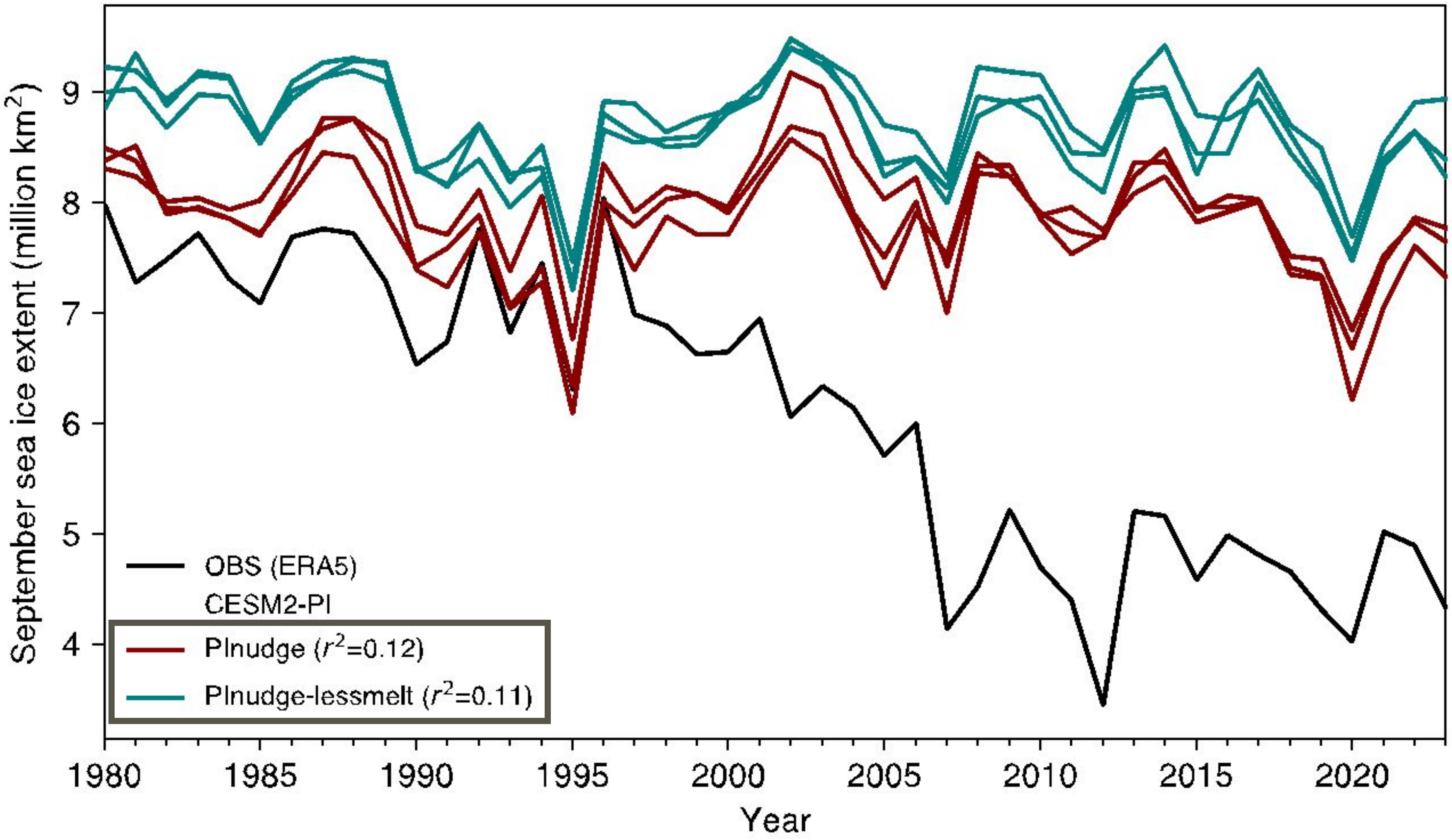
Winds alone **cannot** reproduce observed annual and monthly warming

Winds alone **can** explain 24% of interannual variability and seasonal patterns of warming

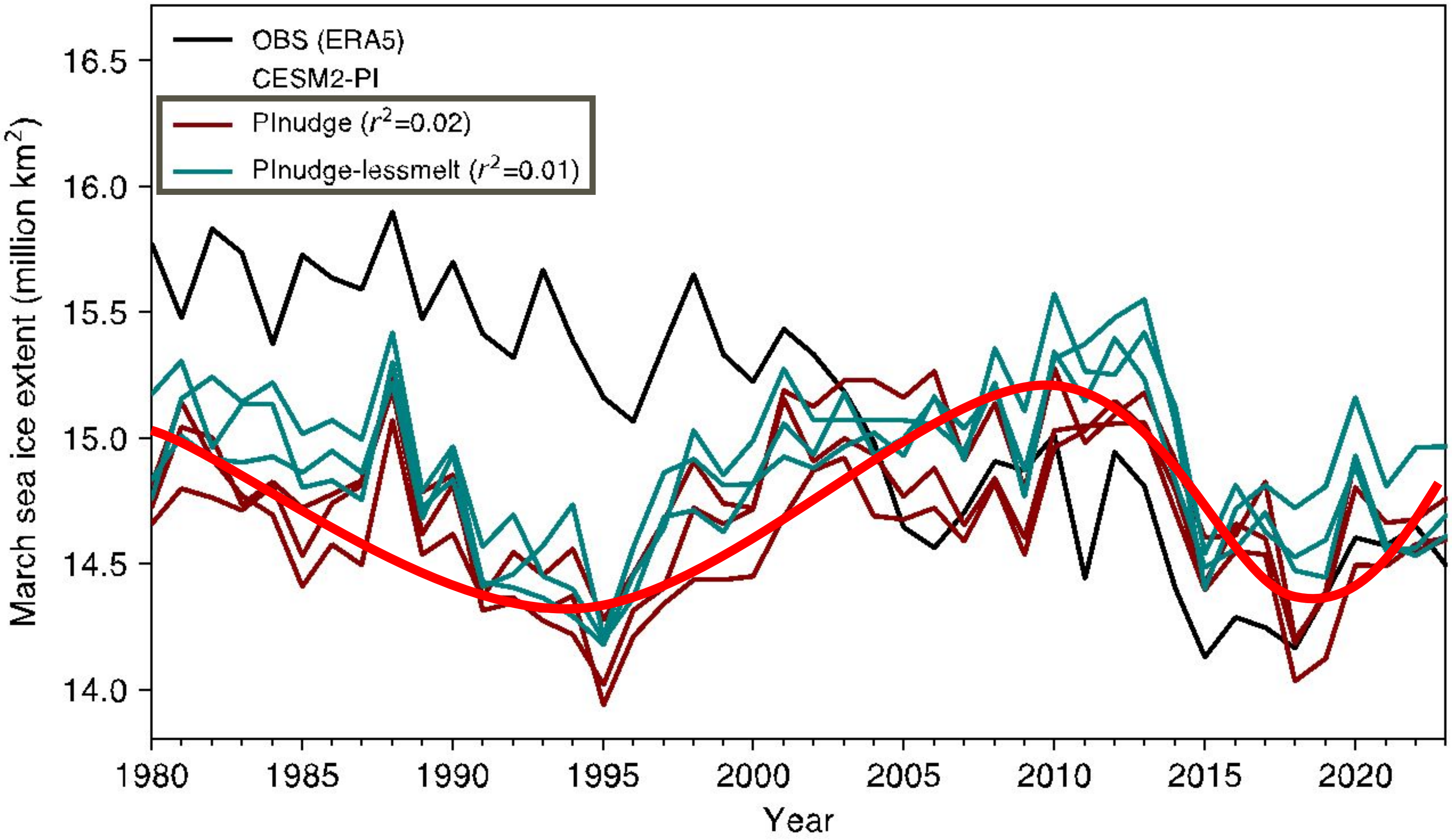
Warming is independent of mean state sea ice thickness

Arctic Sea Ice Area Trends & Variability

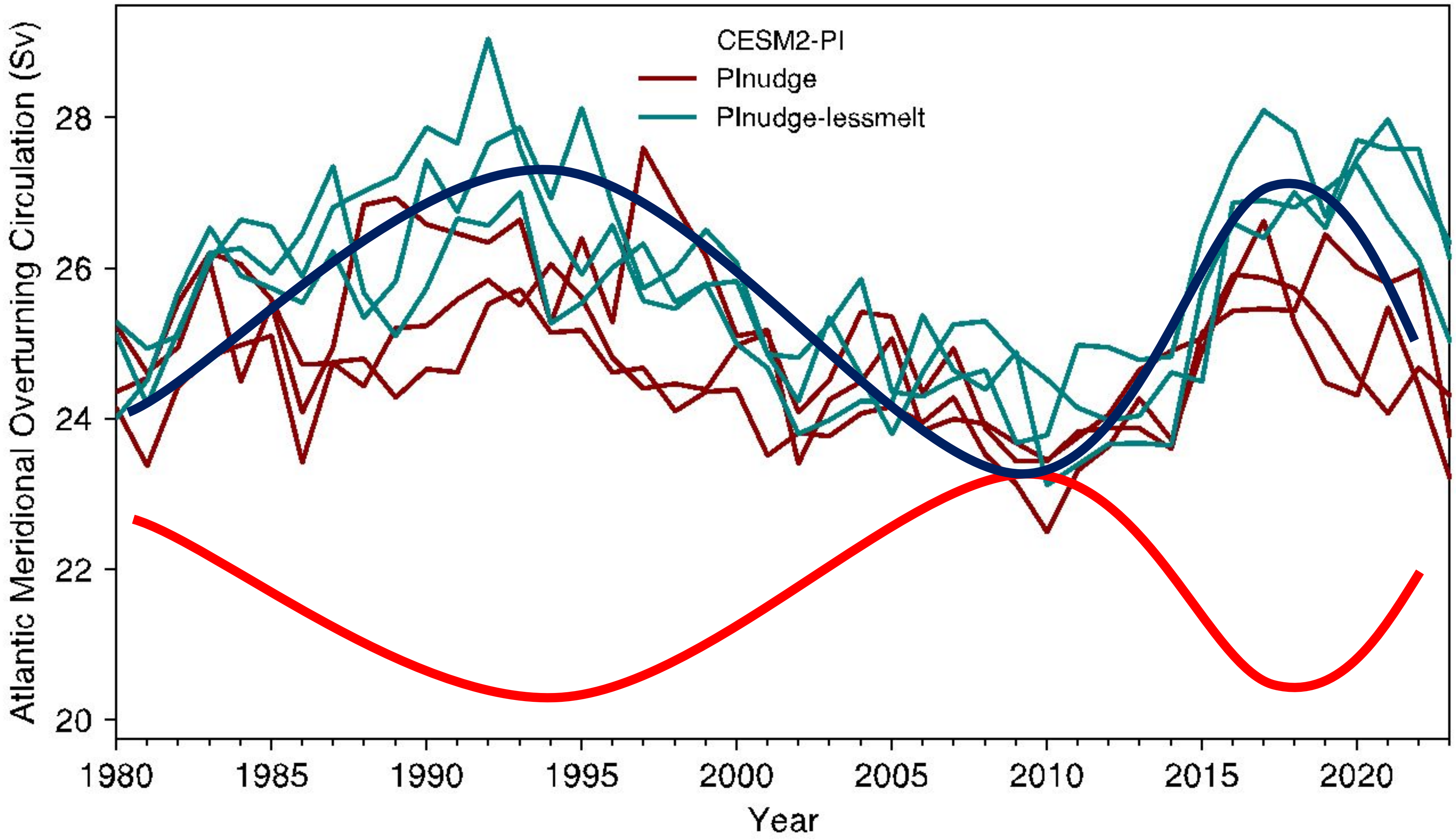
September sea ice area



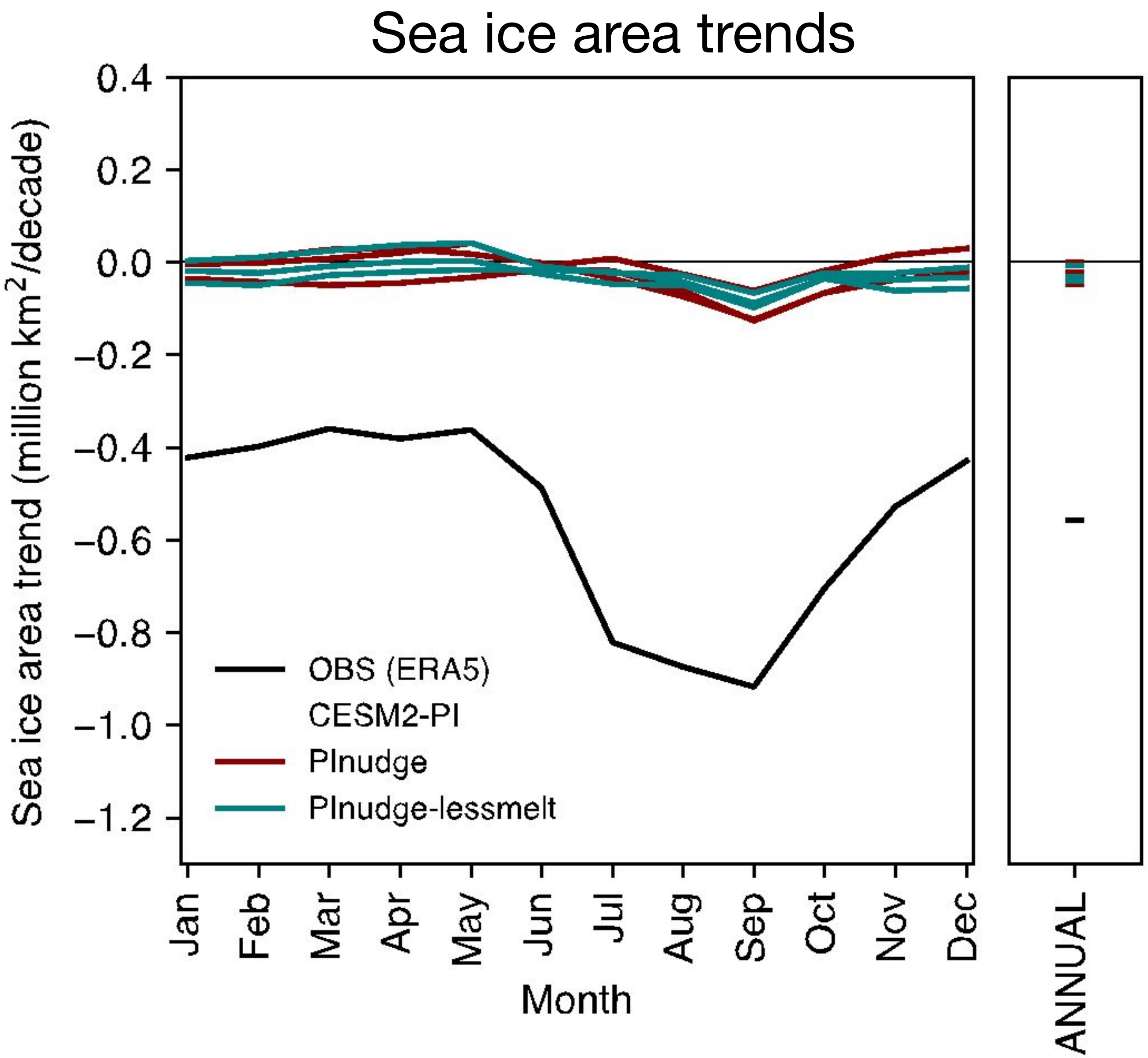
March sea ice area



Atlantic Meridional Overturning Circulation (AMOC)



March sea ice oscillation



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
-0.92 million km^2/decade	-0.36 million km^2/decade

Winds alone **cannot** reproduce observed September, March, and monthly sea ice loss

Winds alone **can** explain 12% to 1% of interannual variability and seasonal patterns of sea ice loss

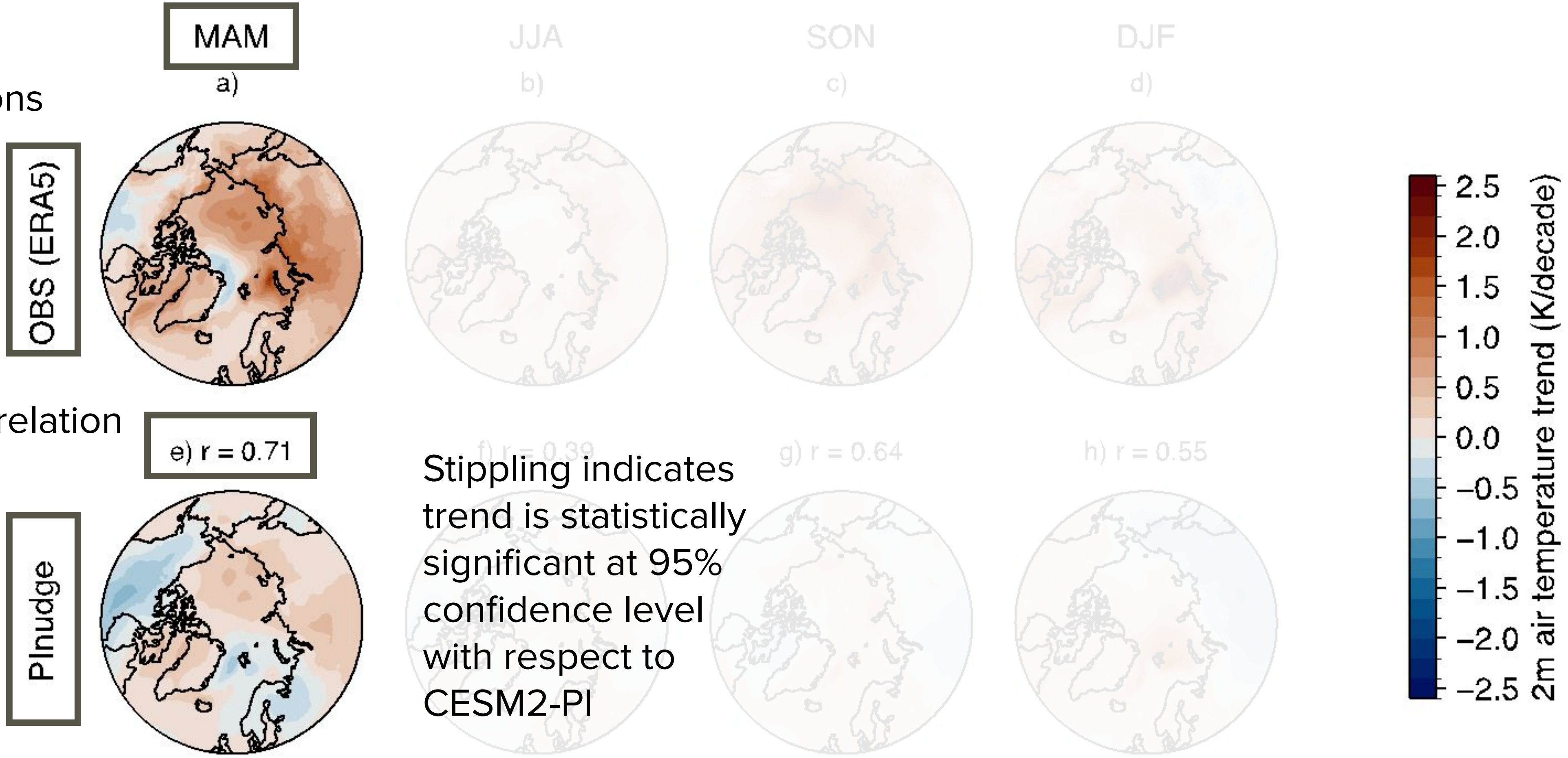
Sea ice loss is independent of mean state sea ice thickness

Local Temperature & Sea Ice Trends

Season

Observations

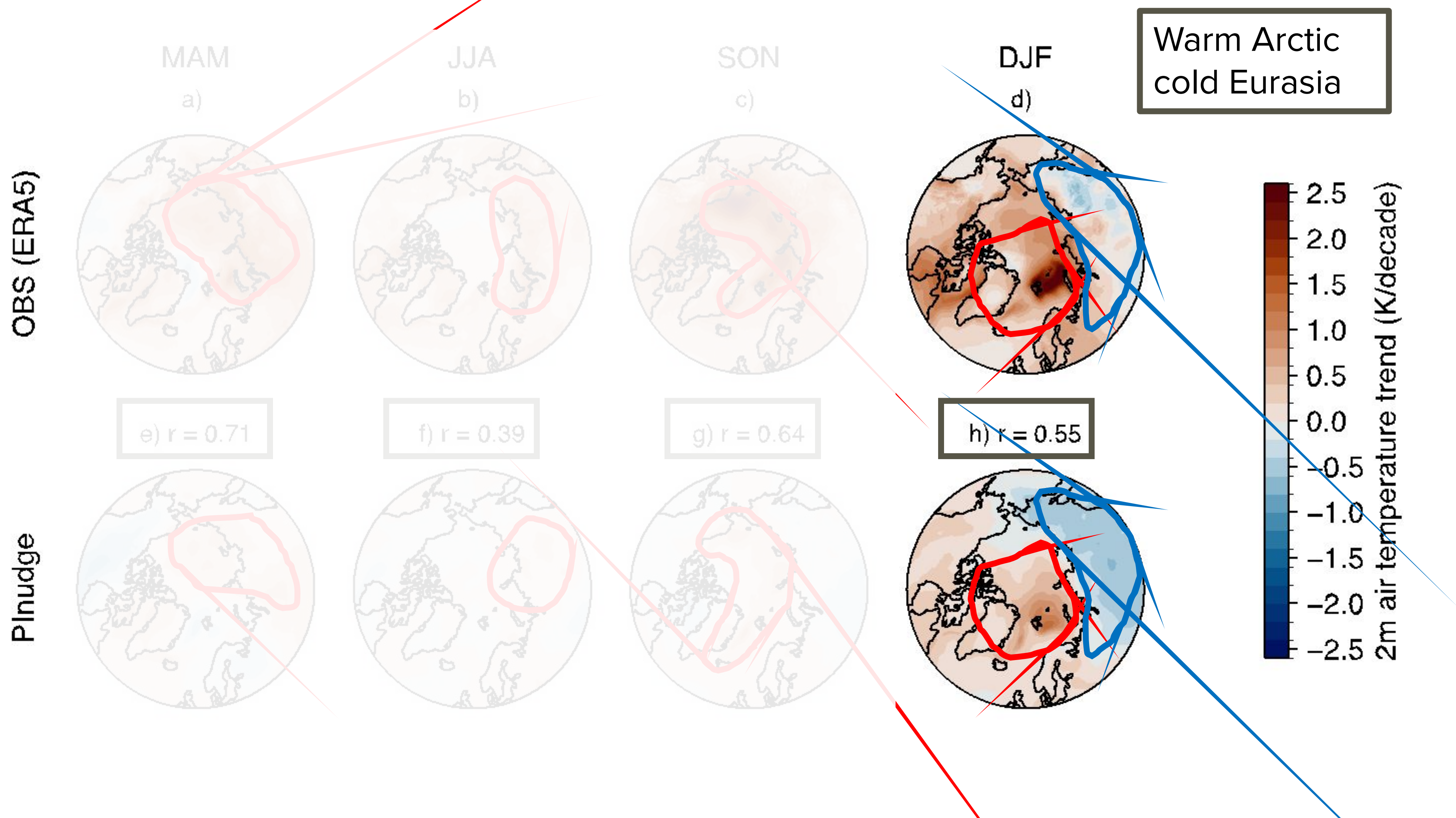
Pattern correlation with OBS



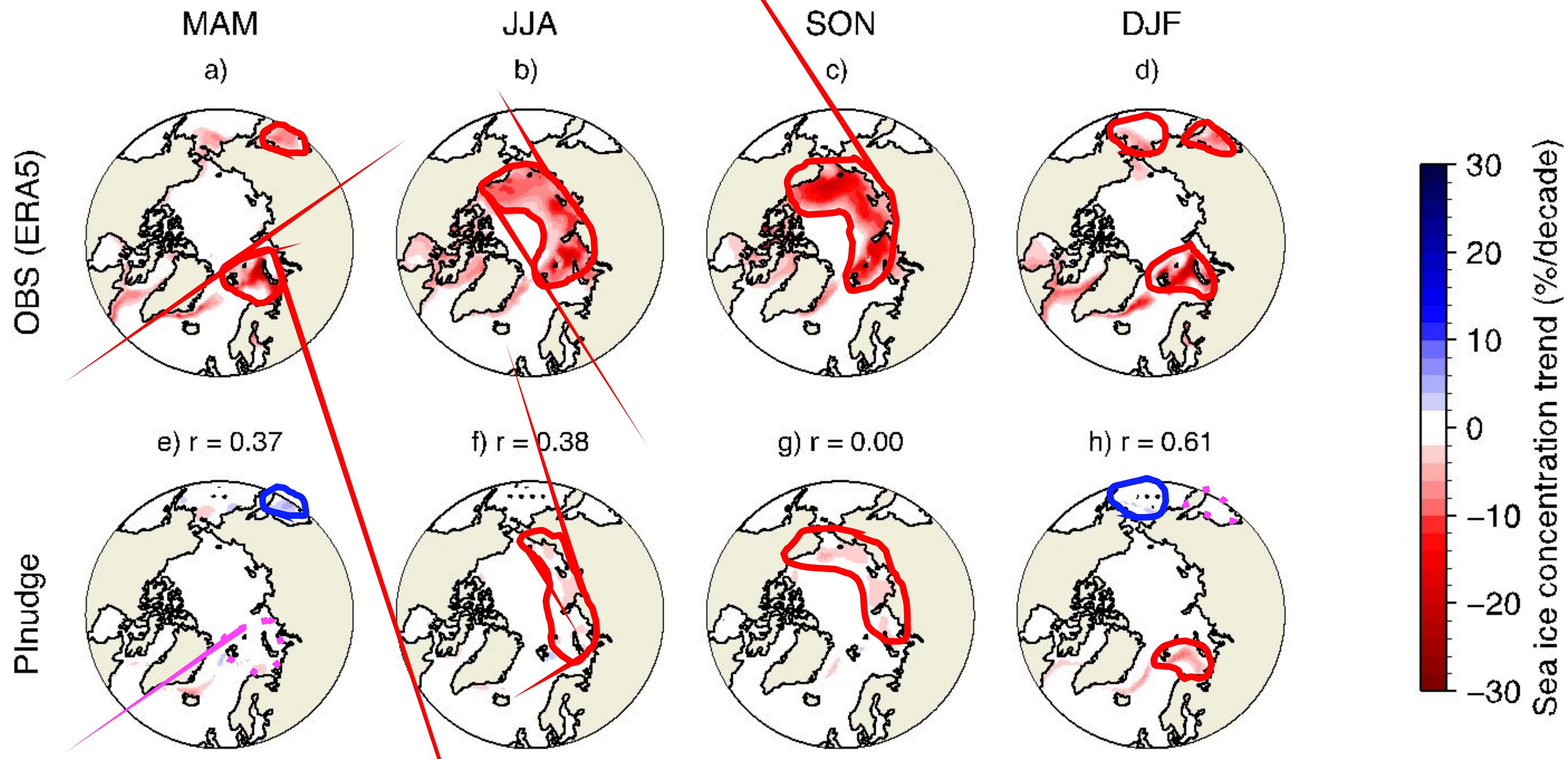
Stippling indicates trend is statistically significant at 95% confidence level with respect to CESM2-PI

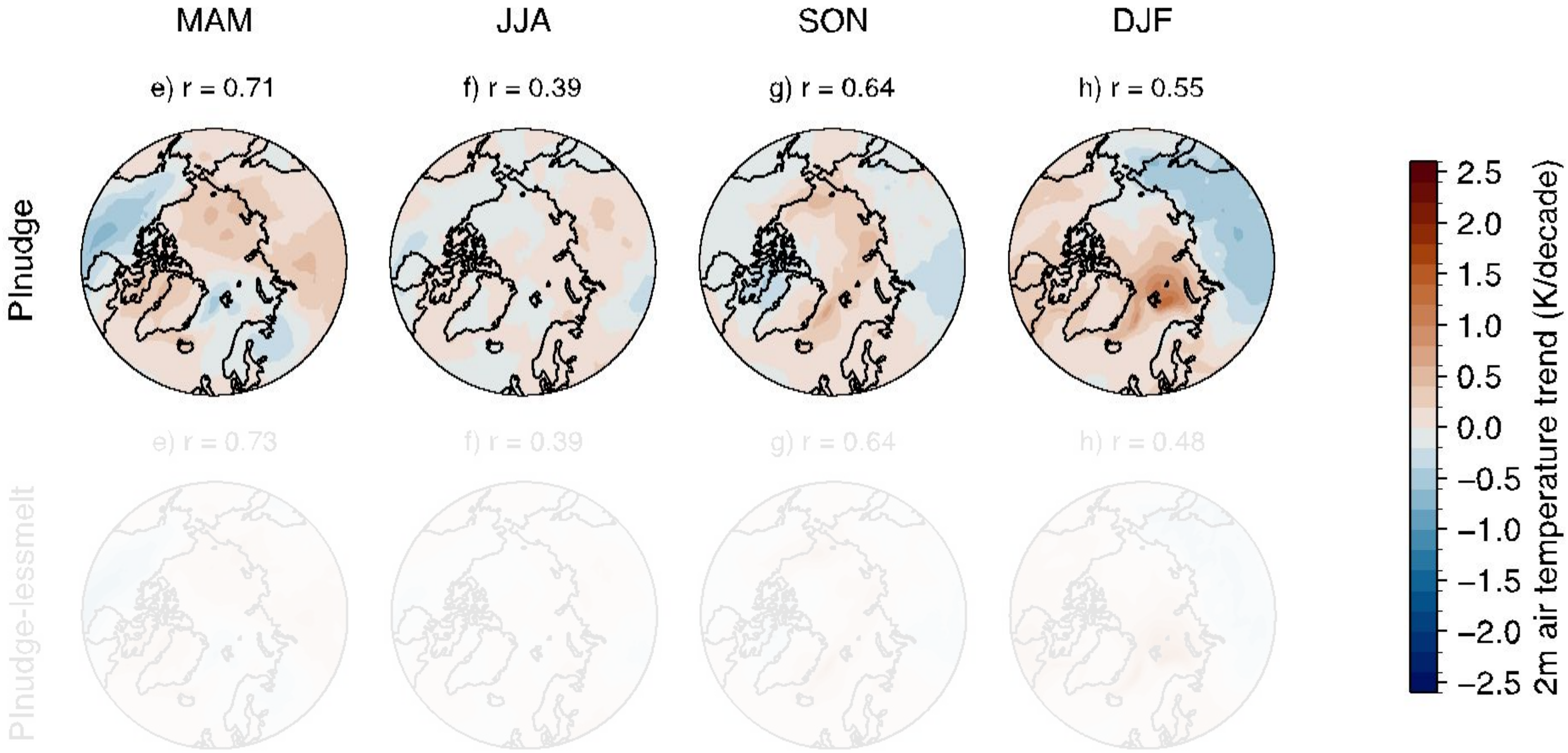
Wind-nudged experiment

Winds drive location of strongest warming in every season

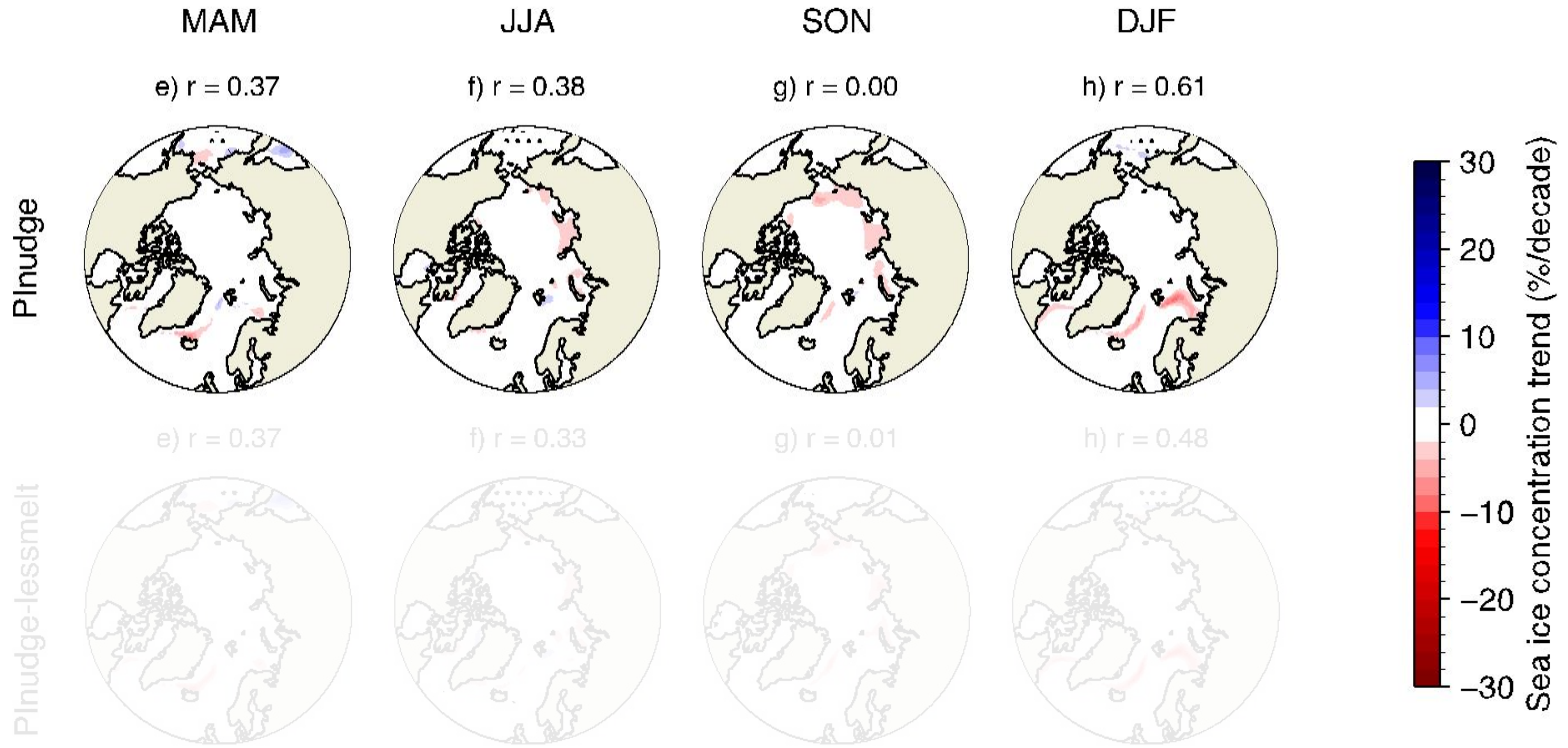


Winds seasonally drive location of strongest sea ice loss





MAM
JJA
SON
DJF
e) r = 0.71
f) r = 0.39
g) r = 0.64
h) r = 0.55
PInudge
e) r = 0.73
f) r = 0.39
g) r = 0.64
h) r = 0.48
PInudge-lessmelt
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)


MAM
JJA
SON
DJF
e) r = 0.37
f) r = 0.38
g) r = 0.00
h) r = 0.61
PInudge
e) r = 0.37
f) r = 0.33
g) r = 0.01
h) r = 0.48
PInudge-lessmelt
30
20
10
0
−10
−20
−30
Sea ice concentration trend (%/decade)

Winds alone **cannot** reproduce the magnitude of local warming and sea ice loss

Winds alone **drive** regional patterns of warming, and to a lesser extent, sea ice loss

Local warming & sea ice loss are independent of mean state sea ice thickness

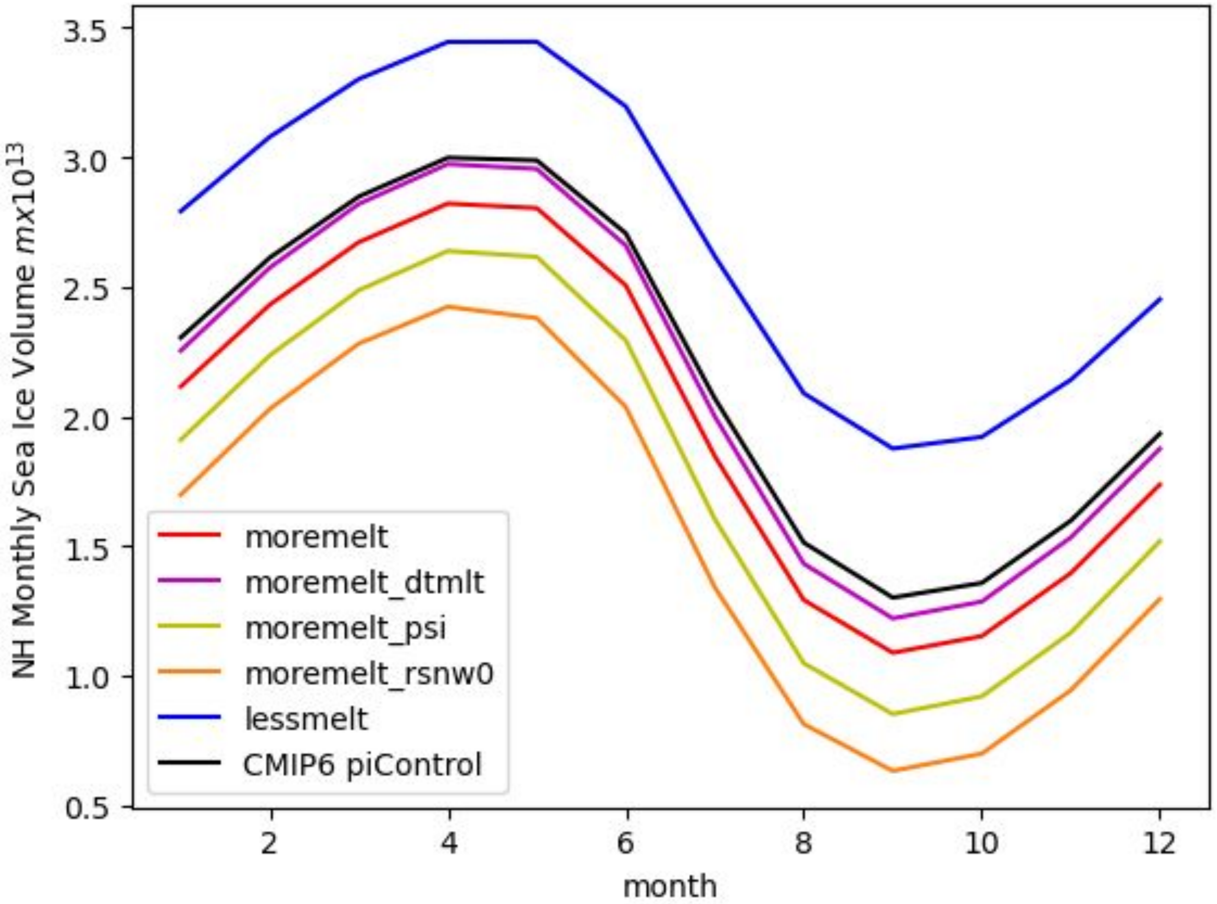
Current work

- Add PInudge-moremelt experiment explore mean state sea ice thickness for thinner sea ice
- Investigating which parameter combination is best for moremelt pre-industrial control

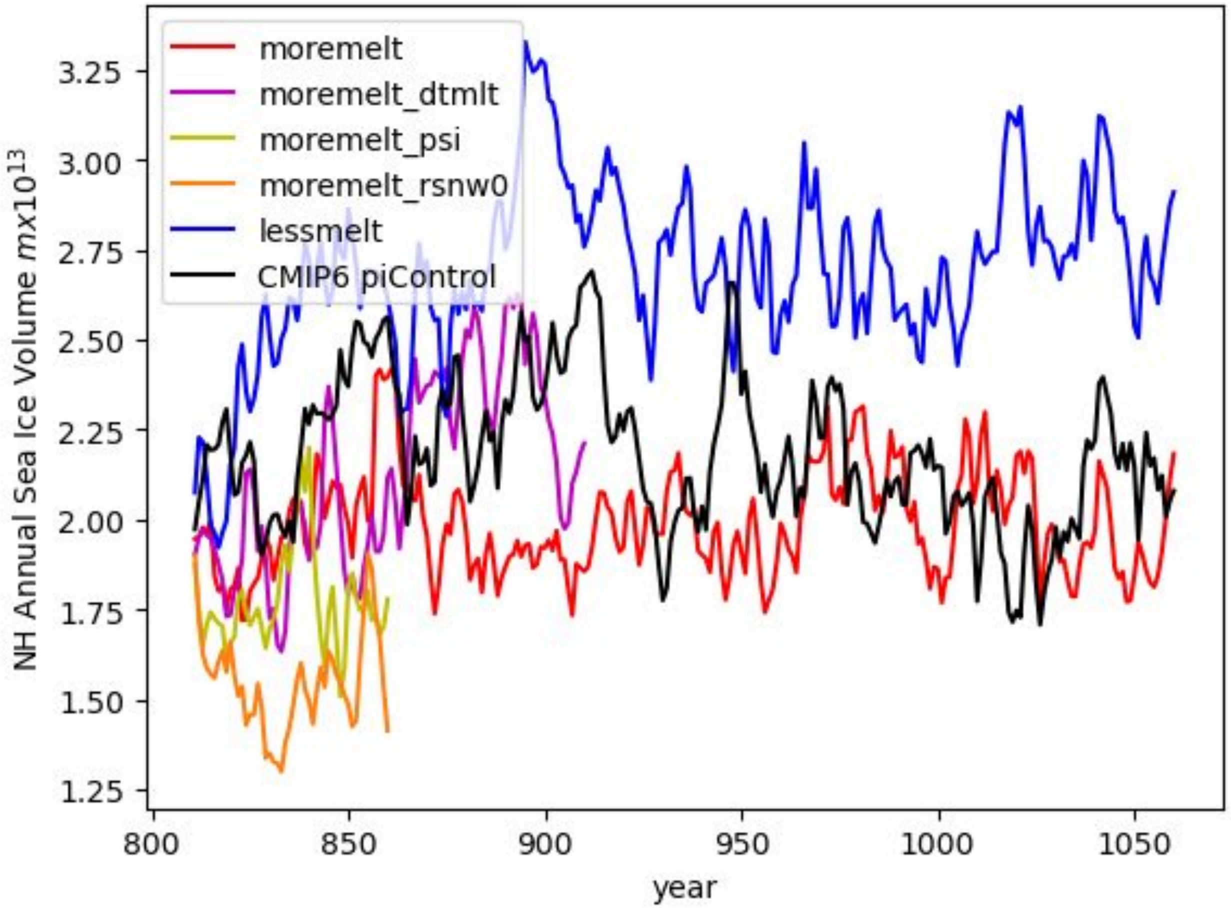
Run name	CICE Namelist modifications	Run duration
moremelt	r_snw = 1.0	250 years
moremelt_dtmlt	r_snw = 1.0 dt_mlt = 2.0	100 years
moremelt_psi	r_snw = 1.0 dt_mlt = 2.0 r_ice = -1.0 r_pnd = -1.0	50 years (+50 years yet to be processed)
moremelt_rsnw0	r_snw = 0.0	50 years (+50 years yet to be processed)

Current work

Arctic Monthly Sea Ice Volume

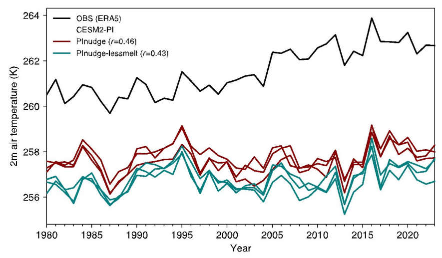


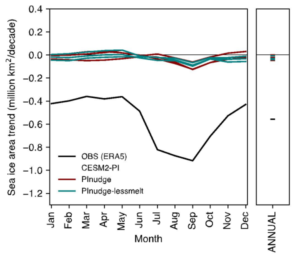
Arctic Annual Average Sea Ice Volume

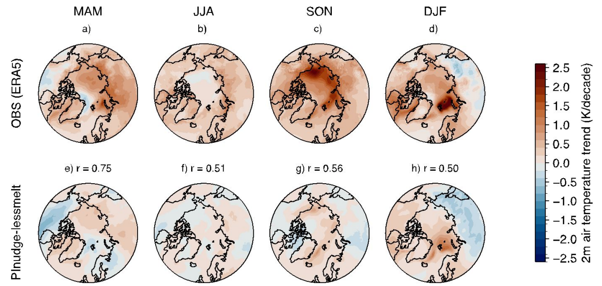


Conclusions

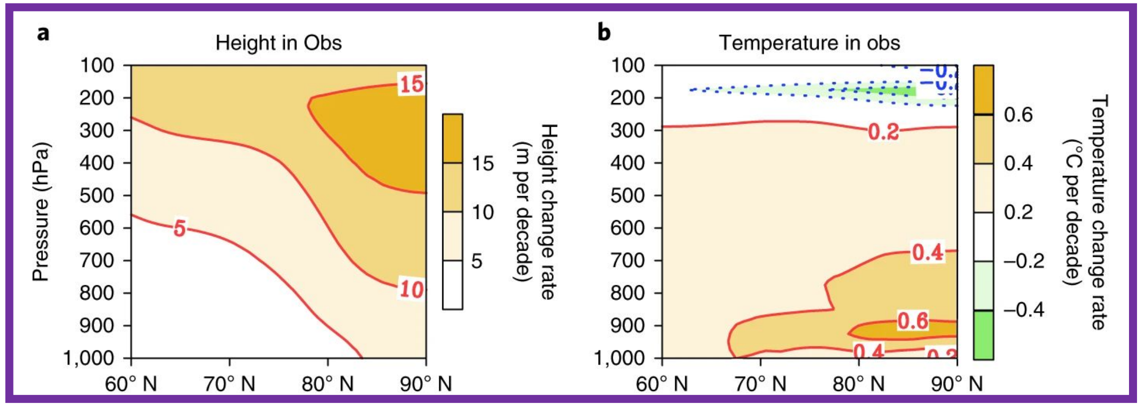
- Observed winds fail to reproduce the magnitude of recent (1980-2023) Arctic warming & sea ice loss
- Observed winds partially reproduce the interannual, seasonal, and spatial variability of Arctic temperature & sea ice
- In summary, observed winds drive Arctic variability but not long term trends
-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







Contact info: ash.gilbert@colorado.edu

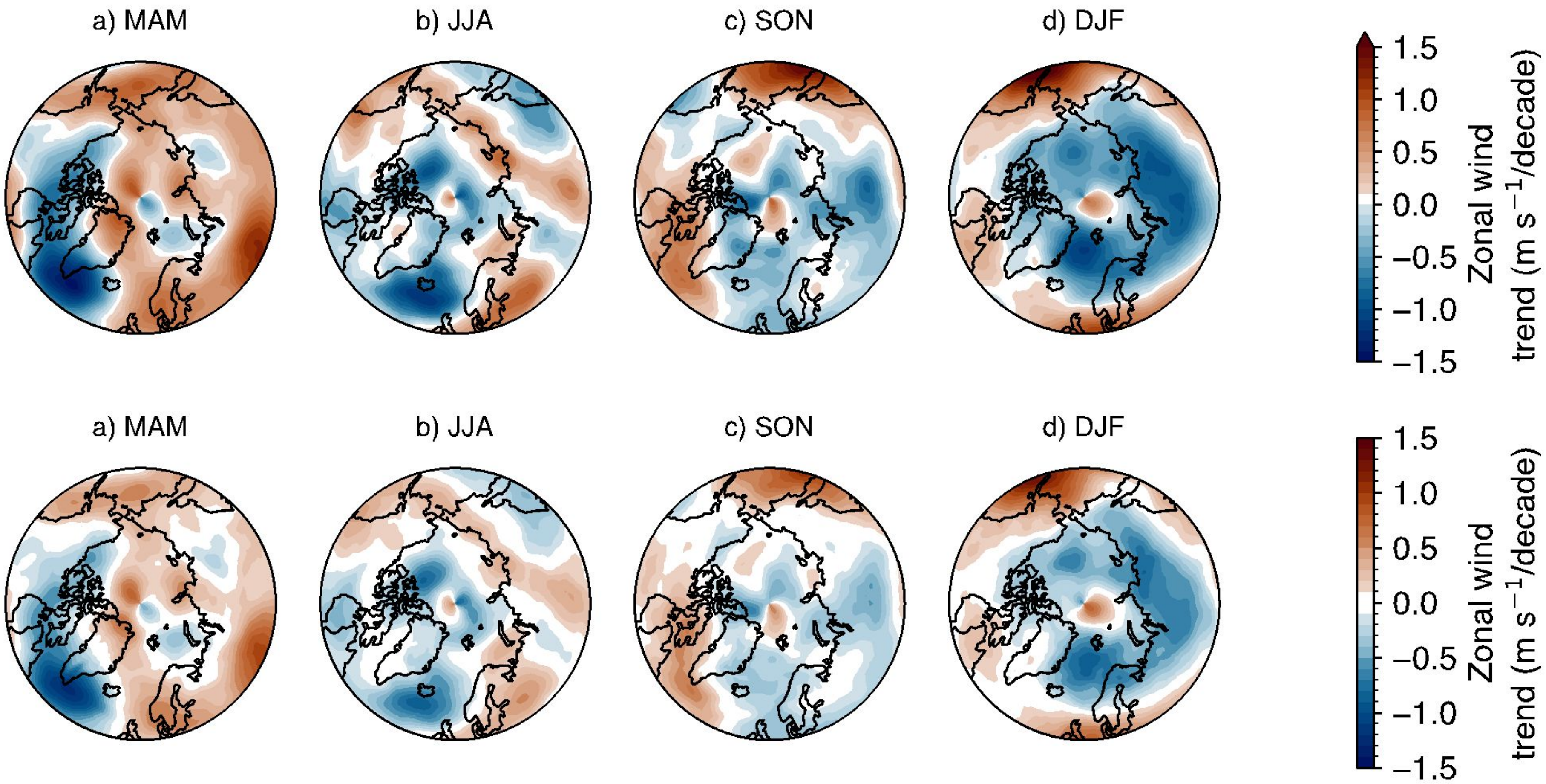


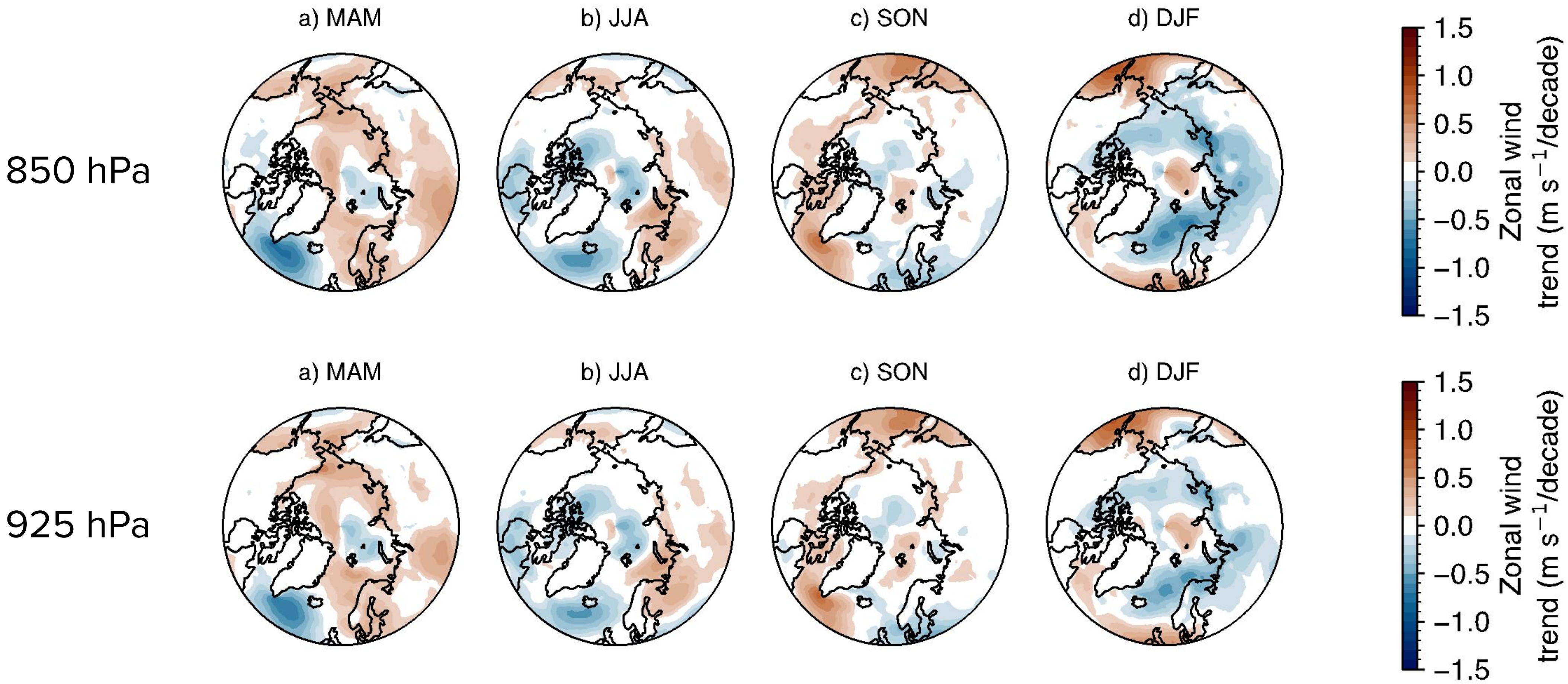
Members with atmospheric circulation closer to observations reproduce observed sea ice loss better

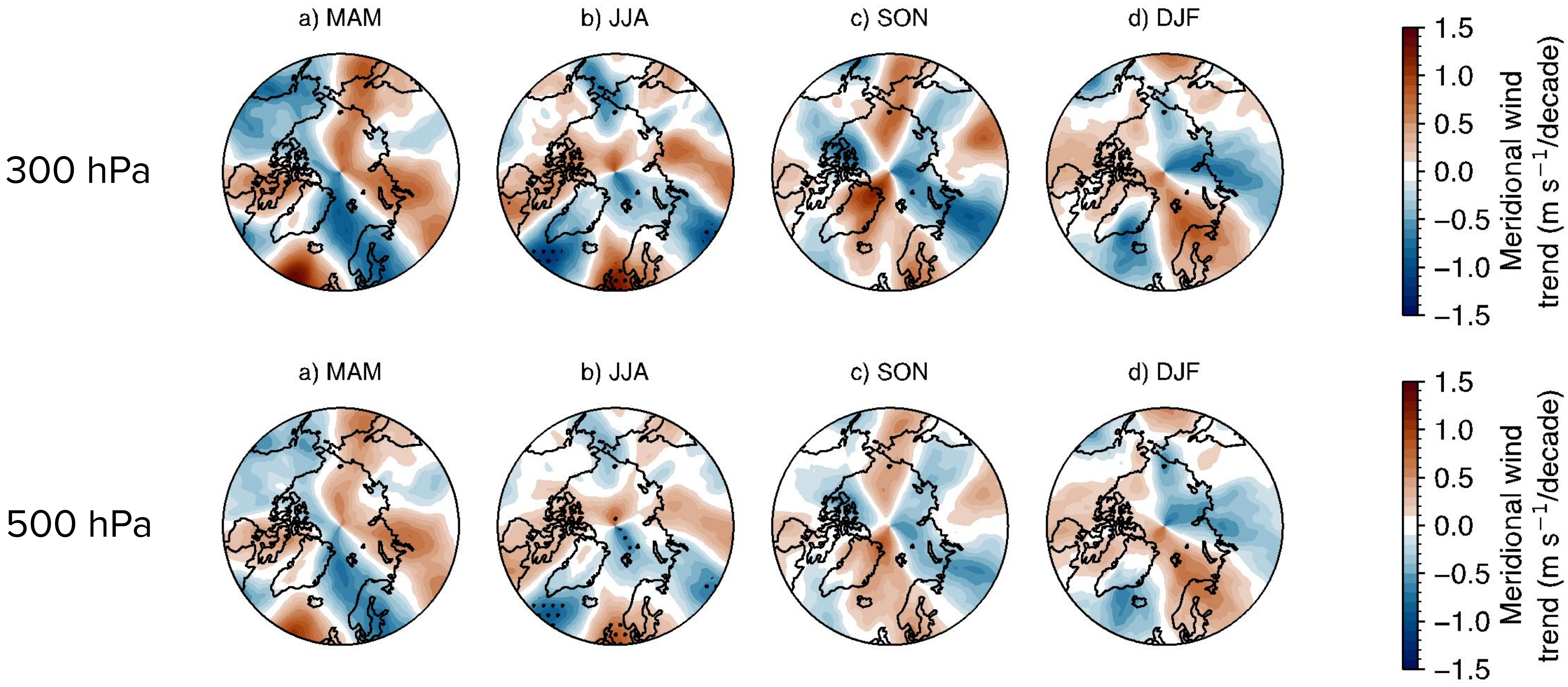
Ding et al. 2019.

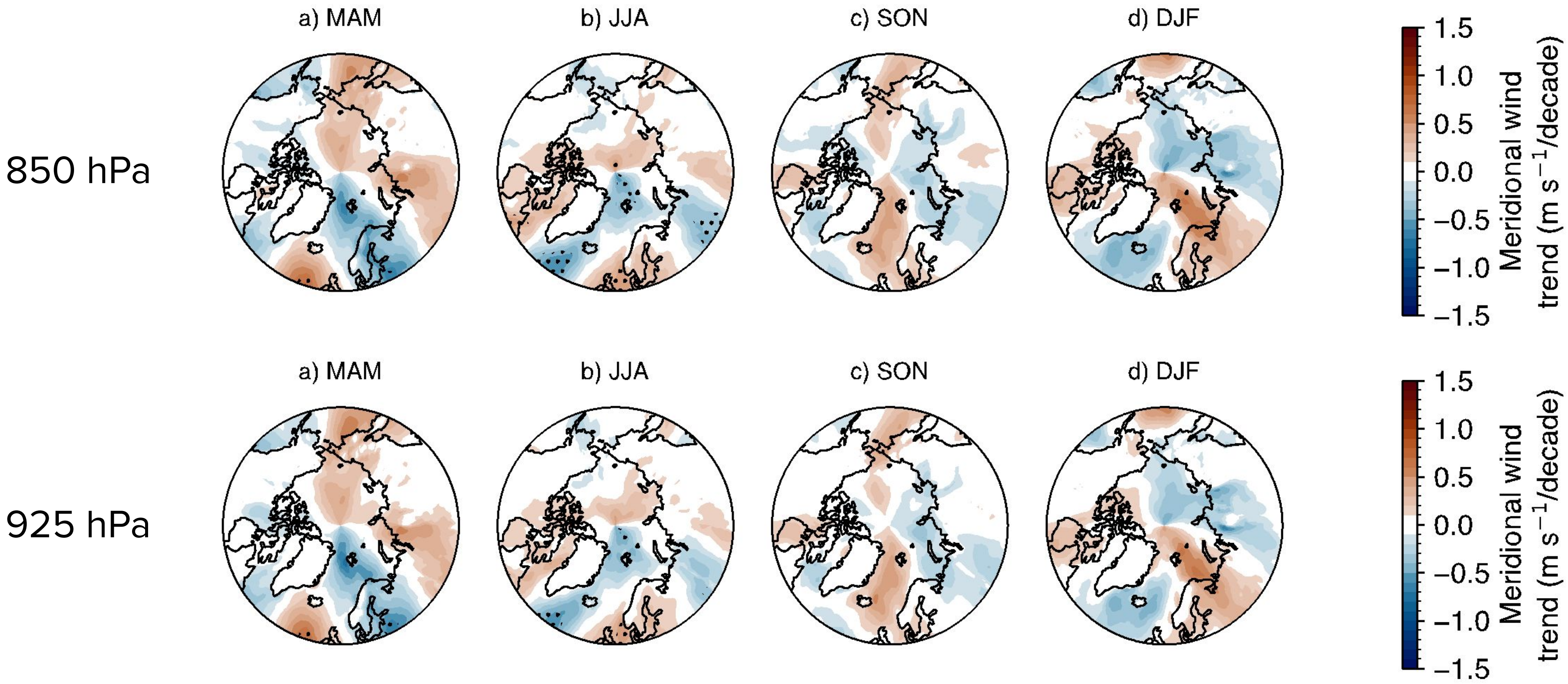
300 hPa

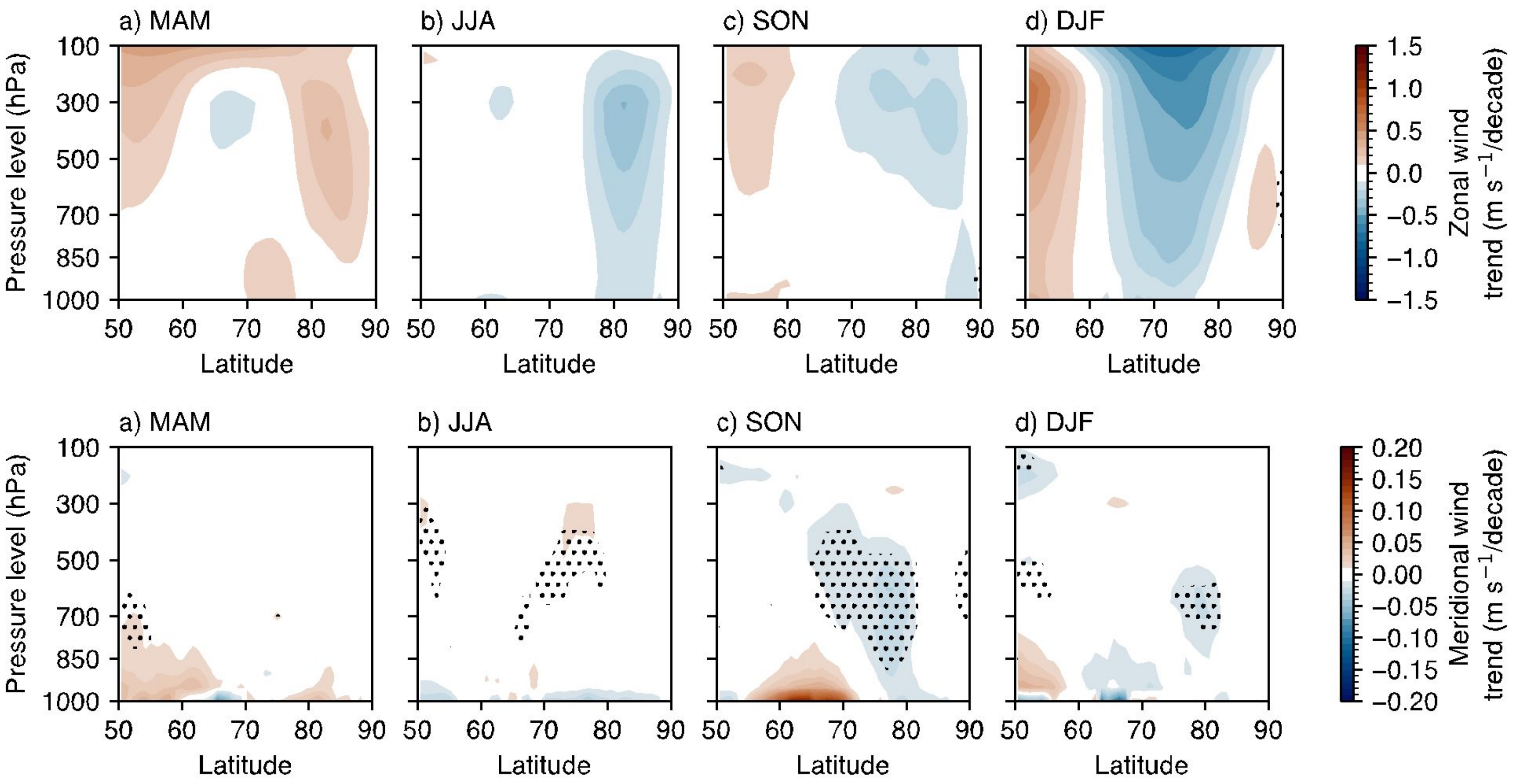
500 hPa



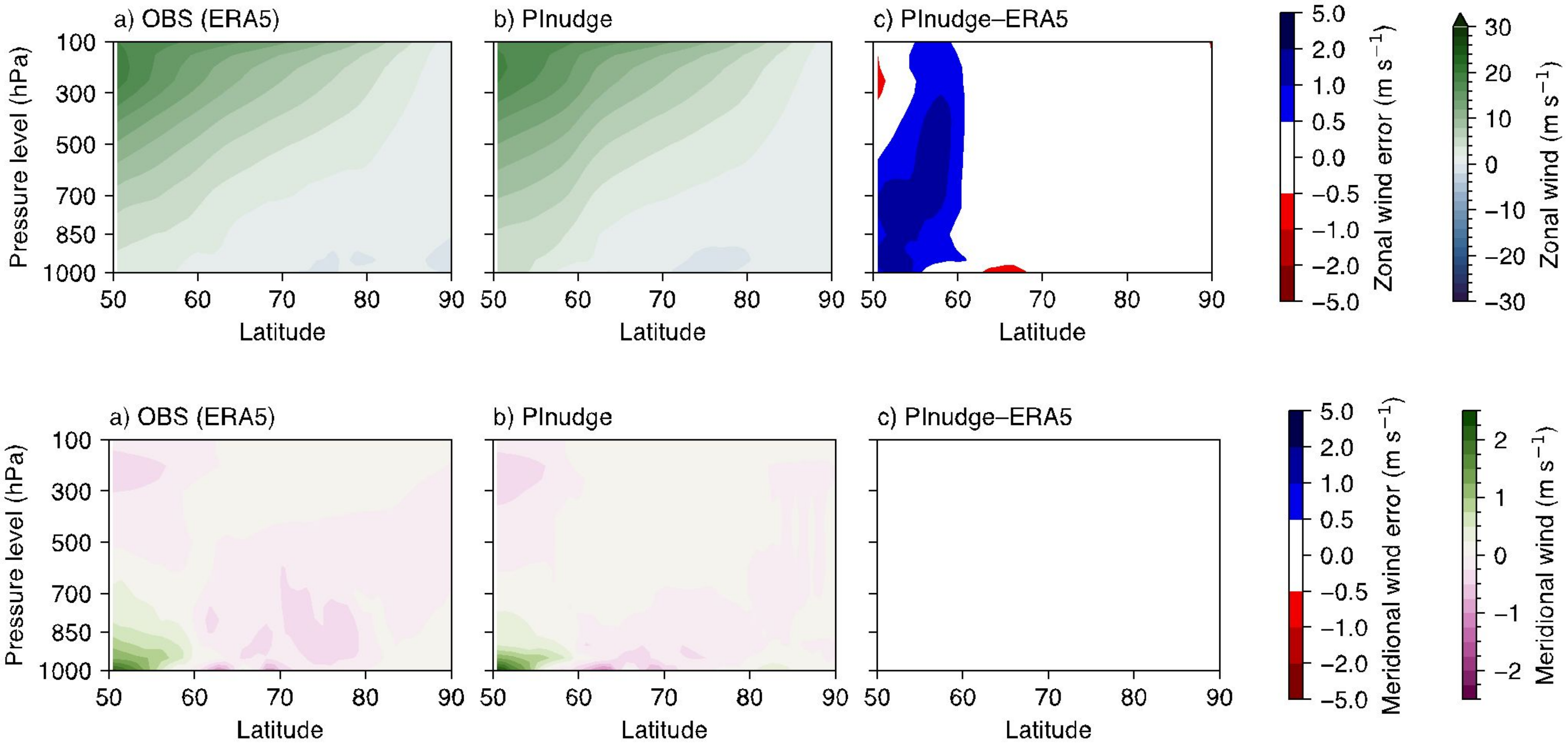

850 hPa
925 hPa
a) MAM
b) JJA
c) SON
d) DJF
a) MAM
b) JJA
c) SON
d) DJF
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
Zonal wind trend (m s−1/decade)
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
Zonal wind trend (m s−1/decade)


300 hPa
500 hPa
a) MAM
b) JJA
c) SON
d) DJF
a) MAM
b) JJA
c) SON
d) DJF
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
Meridional 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
925 hPa
a) MAM
b) JJA
c) SON
d) DJF
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
Meridional wind trend (m s^{-1}/decade)

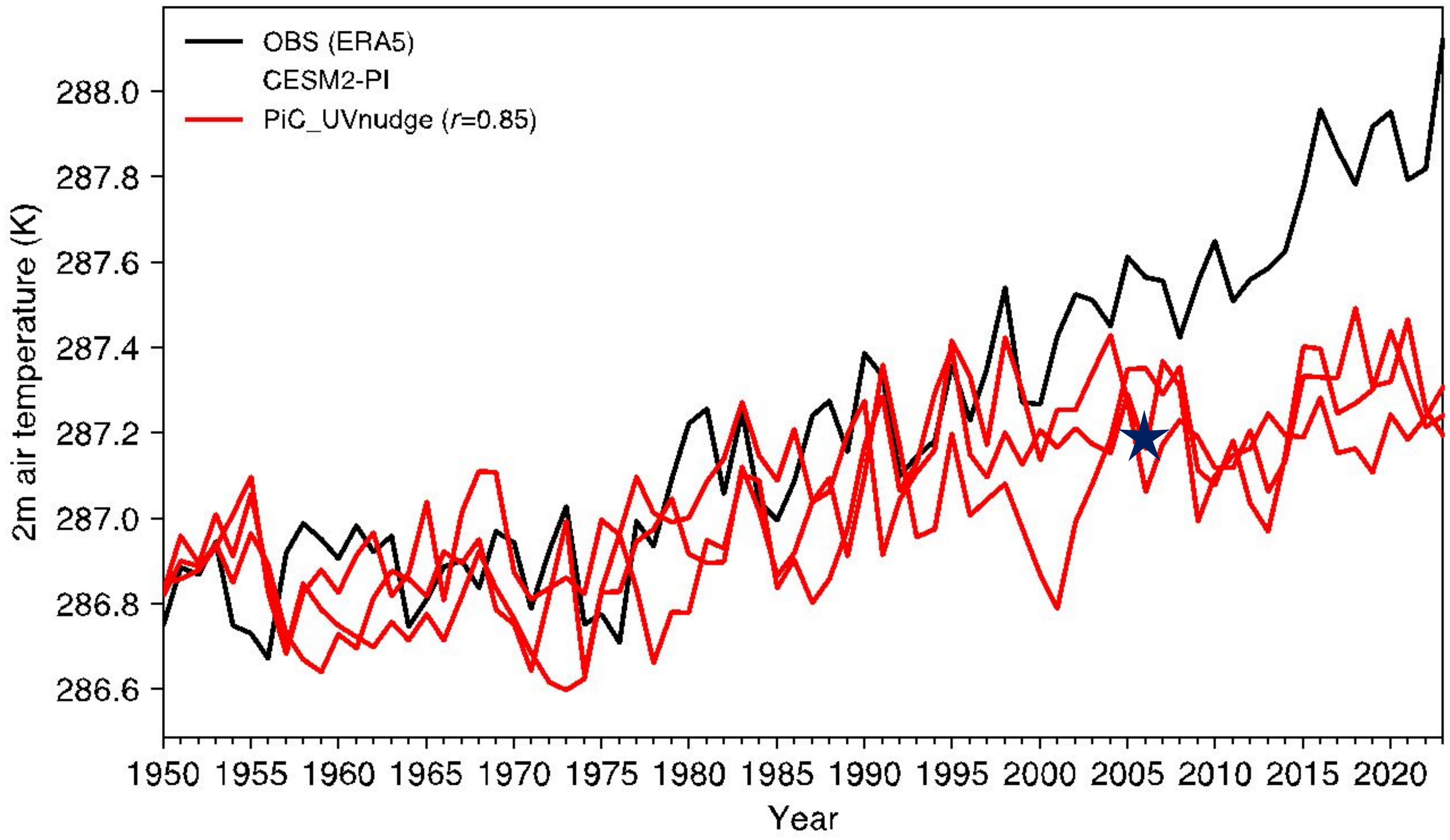

a) MAM
b) JJA
c) SON
d) DJF
Pressure level (hPa)
100
300
500
700
850
1000
50 60 70 80 90
Latitude
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
Zonal wind trend (m s−1/decade)
a) MAM
b) JJA
c) SON
d) DJF
Pressure level (hPa)
Latitude
0.20
0.15
0.10
0.05
0.00
−0.05
−0.10
−0.15
−0.20
Meridional wind trend (m s−1/decade)

Wind nudging in practice...

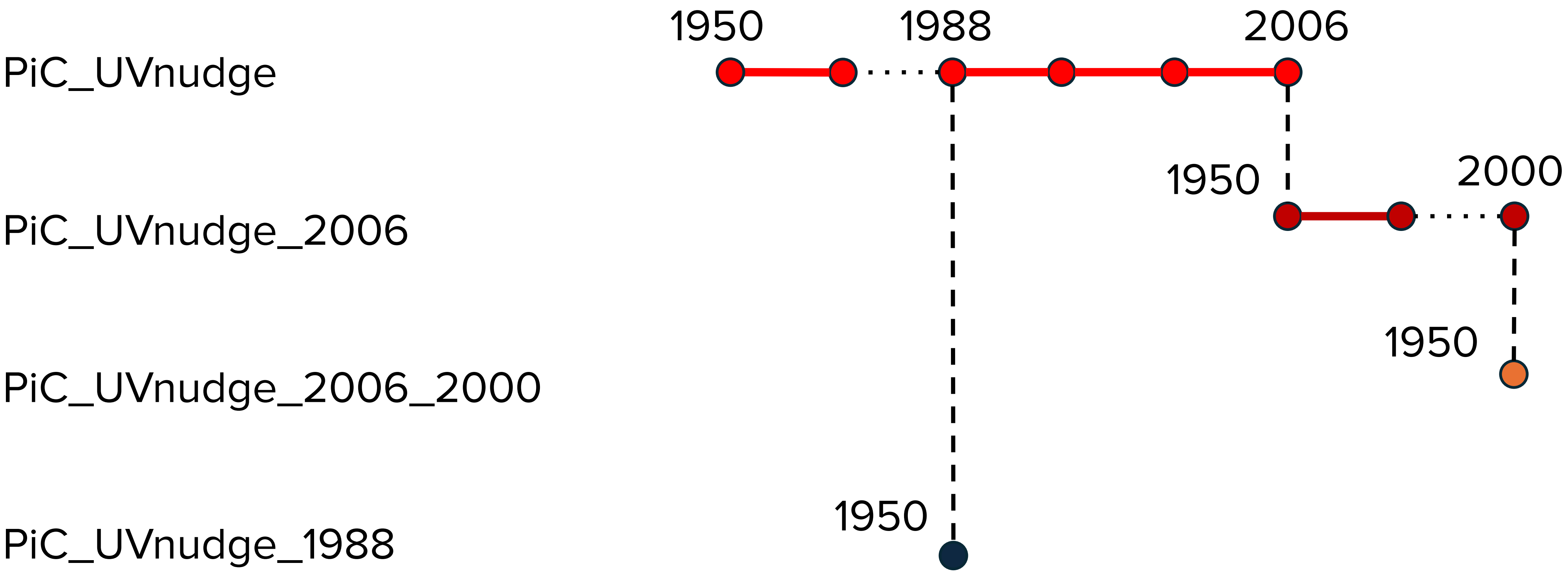


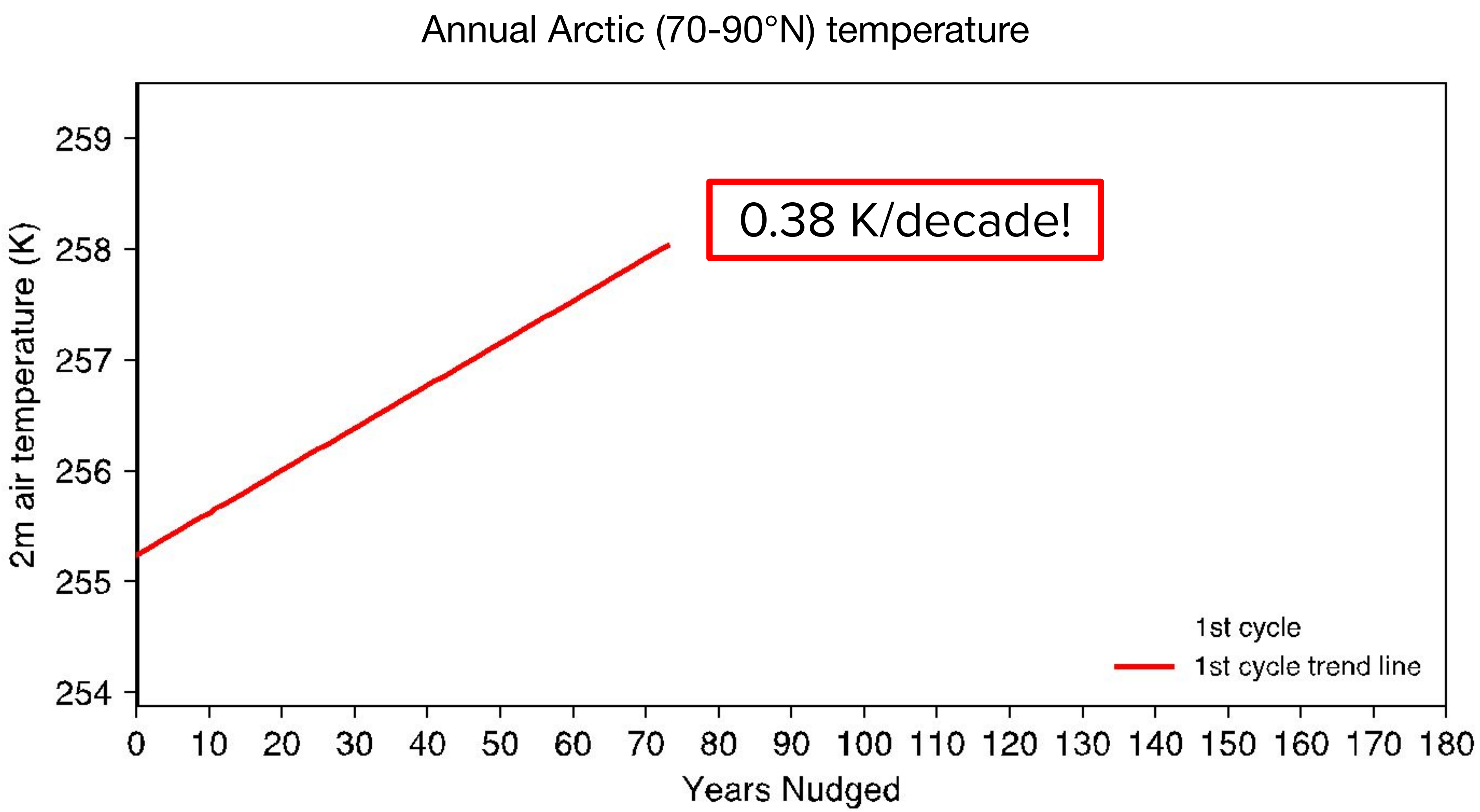
Experiment name	Initial condition	Physics/Namelist changes	Ensemble members	Experiment type
PiC_UVnudge	Year 501 of CESM2 piControl		3	Spin-up
PiC_UVnudge_LM	Year 1181 of CESM2lessmelt piControl	Lessmelt CICE mods	3	Spin-up
PiC_UVnudge_2006 (i.e. PInudge)	Year 2006 of PiC_UVnudge		3	Science
PiC_UVnudge_LM2006 (i.e. PInudge-lessmelt)	Year 2006 of PiC_UVnudge_LM	Lessmelt CICE mods	3	Science
PiC_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

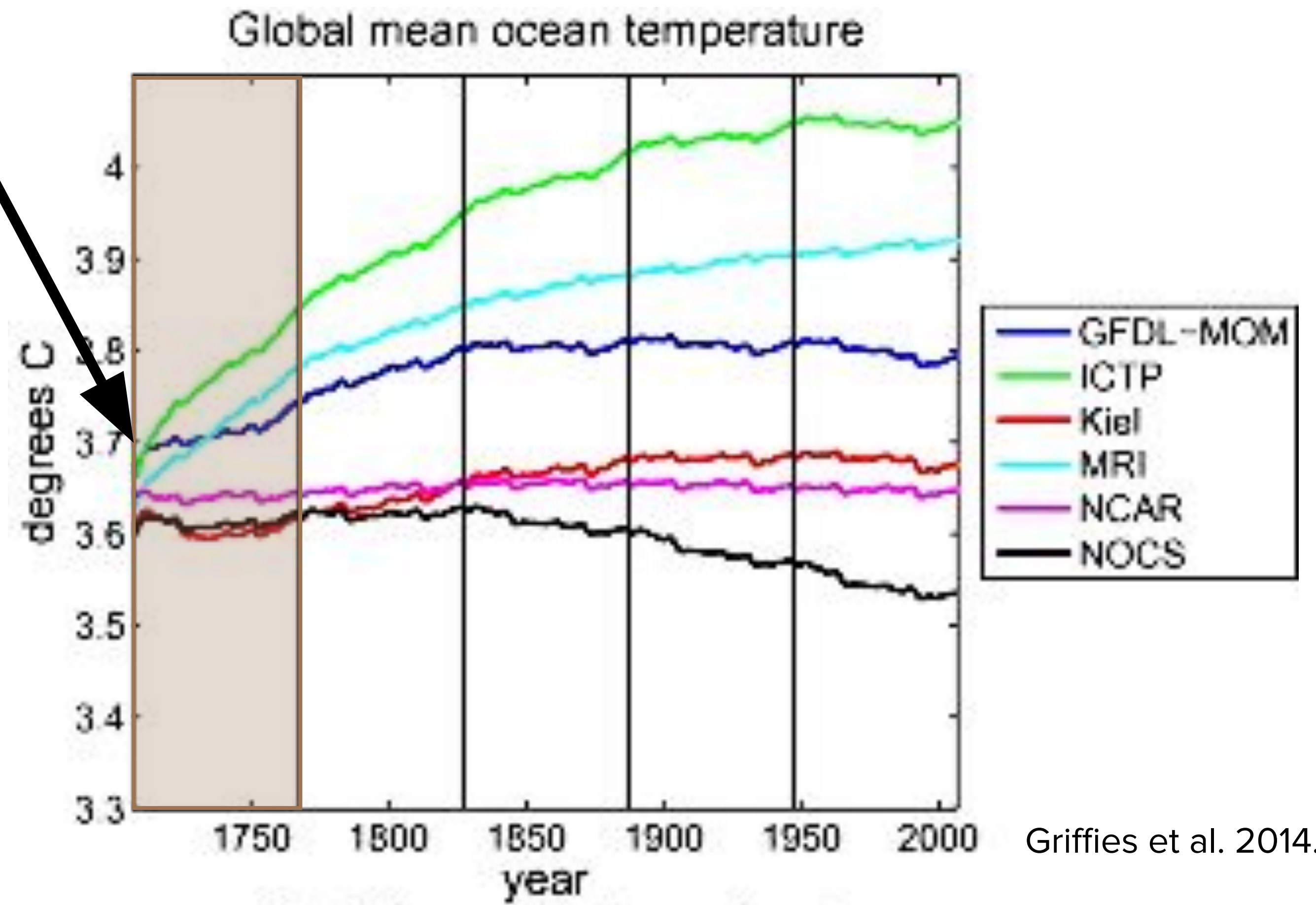
Drift

or

Signal

Cycling atmospheric forcing in ocean models removes model drift

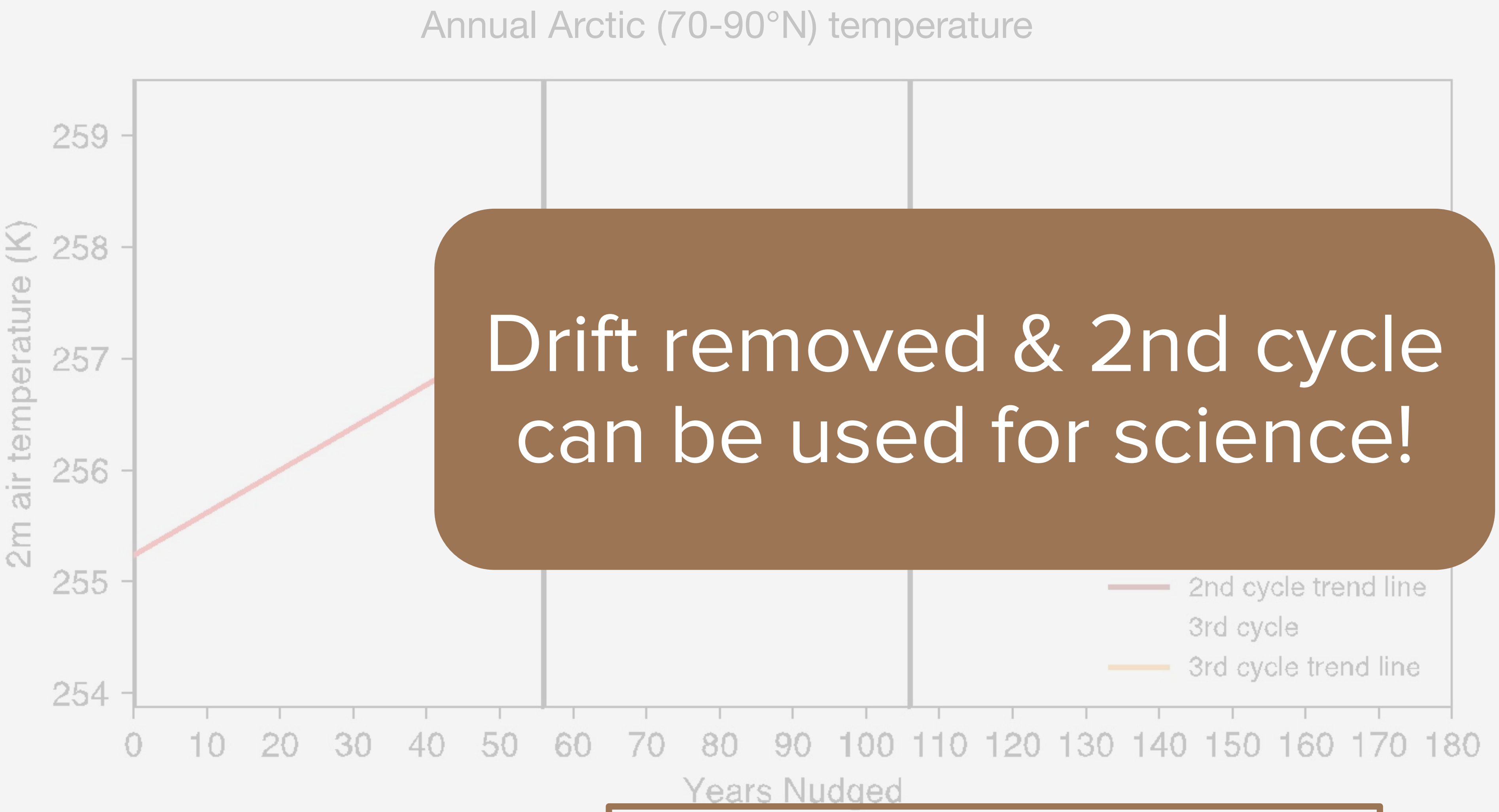
Each box is one cycle of atmospheric forcing



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

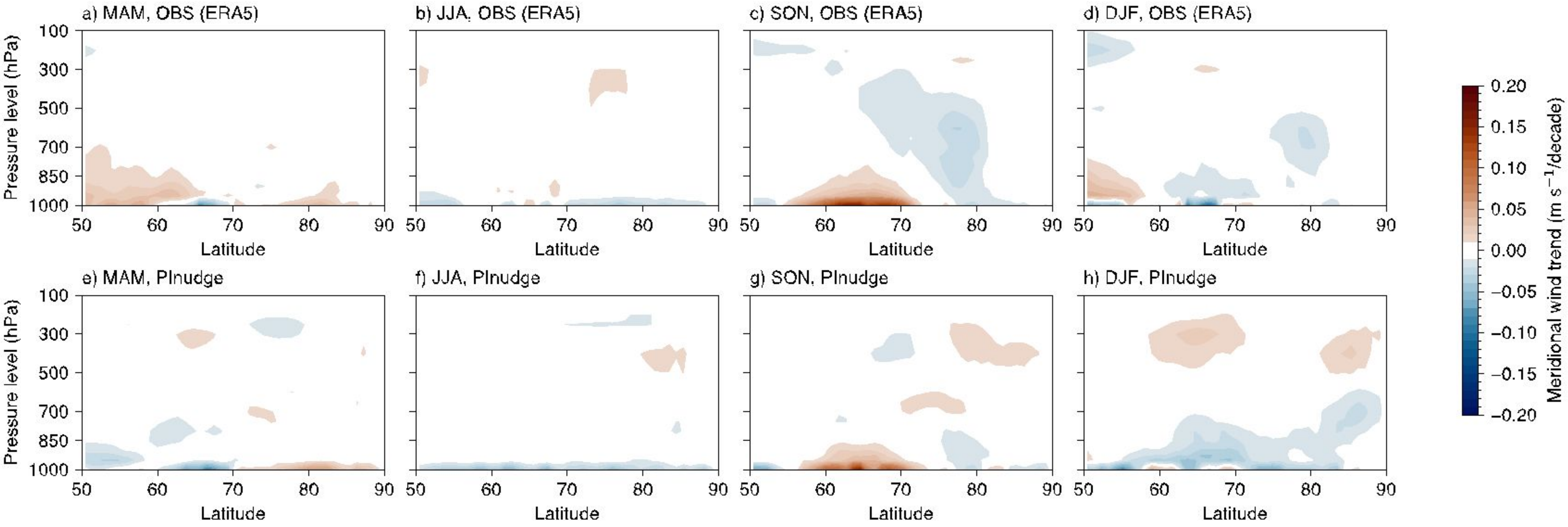
or

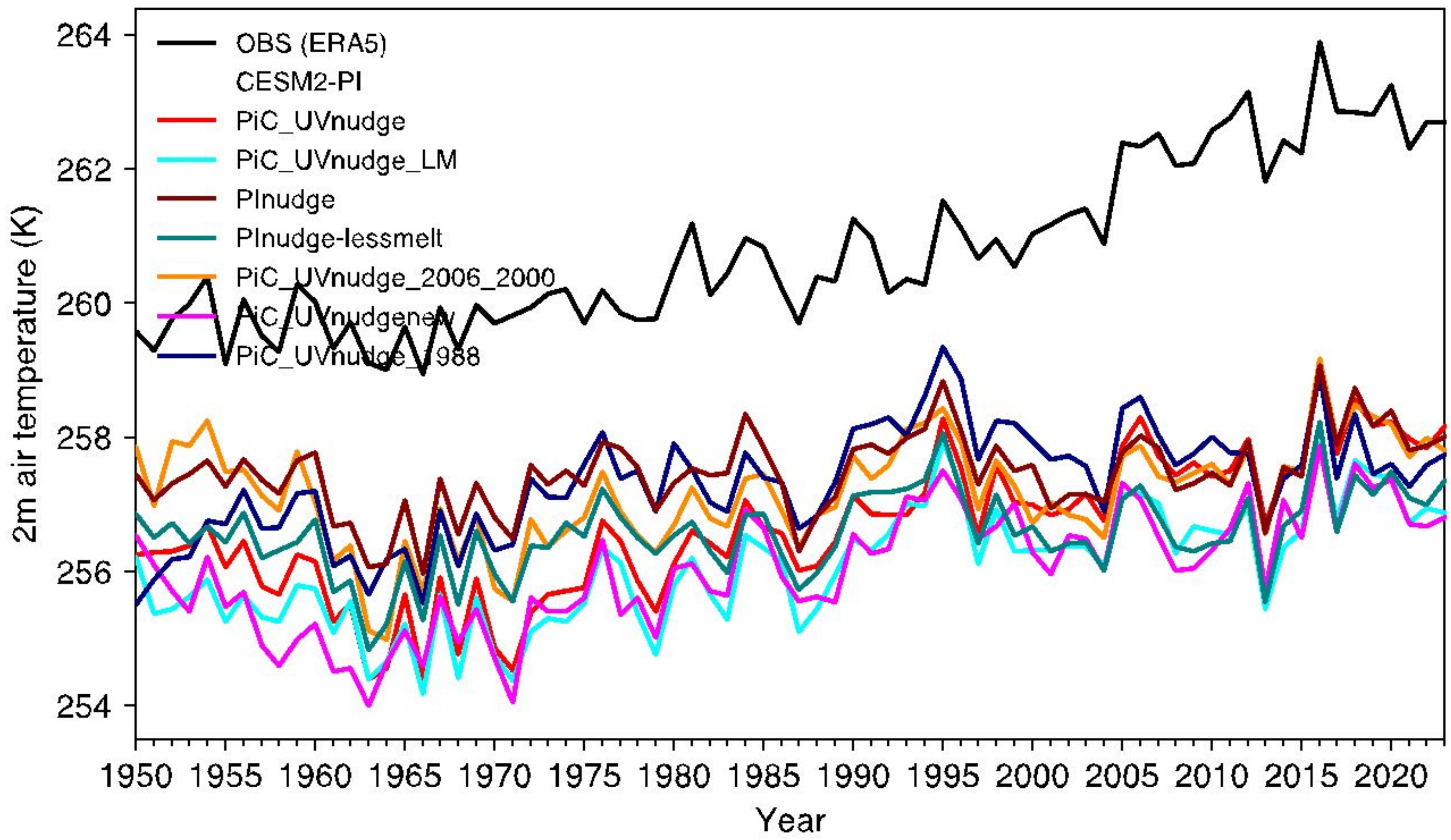
Signal

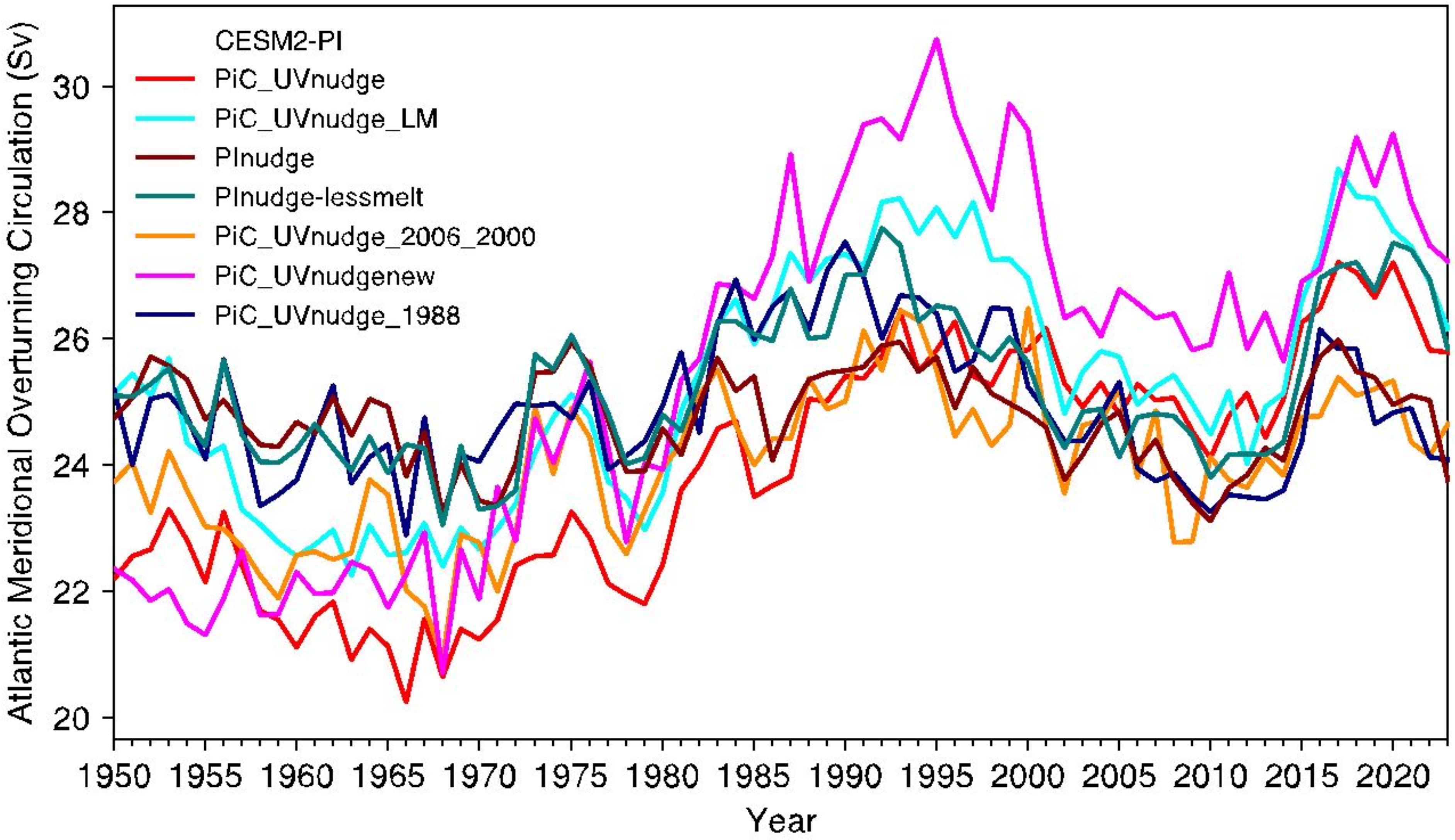
Drift removed & 2nd cycle can be used for science!

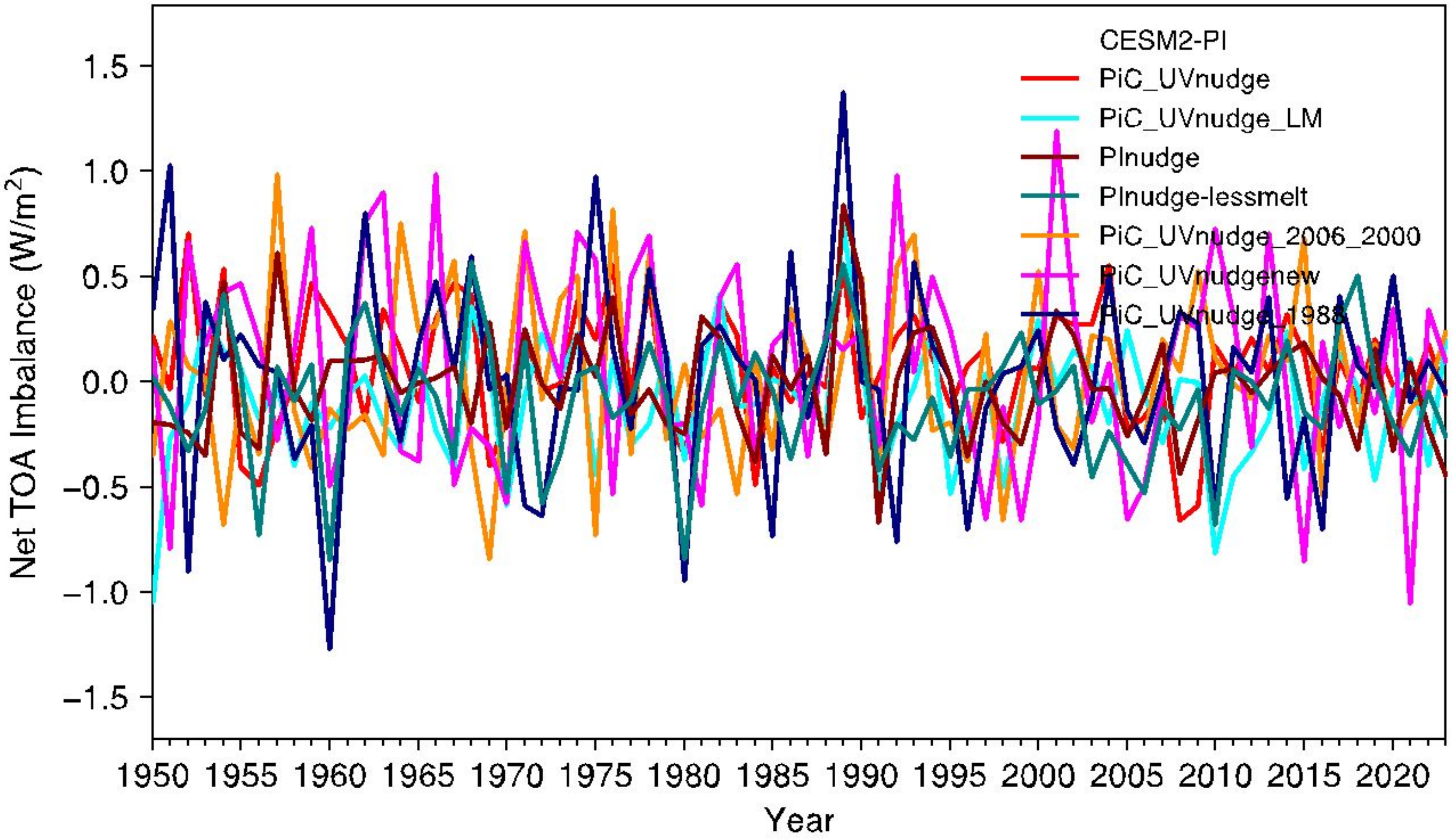
PInudge = 2nd cycle

PInudge-lessmelt = 2nd cycle

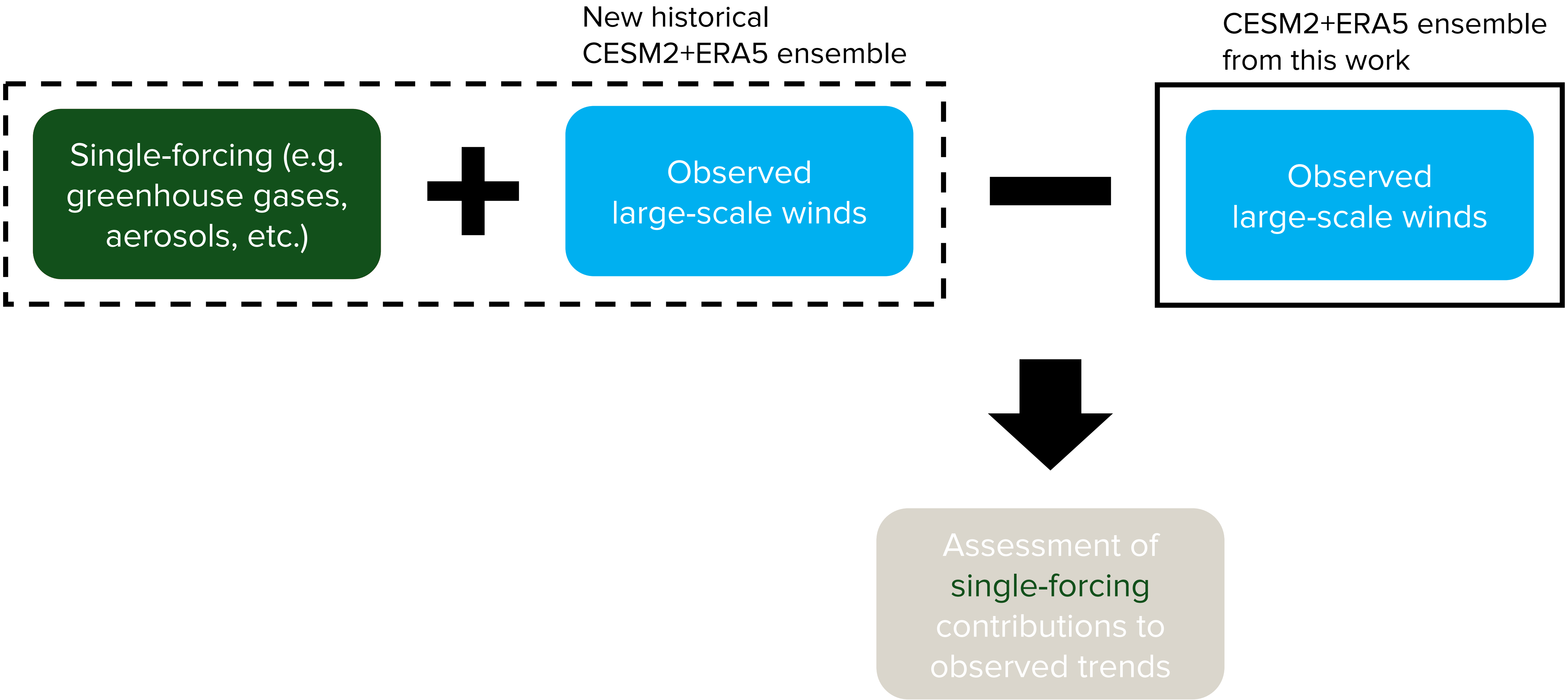

a) MAM, OBS (ERA5)
b) JJA, OBS (ERA5)
c) SON, OBS (ERA5)
d) DJF, OBS (ERA5)
e) MAM, PInudge
f) JJA, PInudge
g) SON, PInudge
h) DJF, PInudge
Pressure level (hPa)
100
300
500
700
850
1000
Latitude
50
60
70
80
90
Meridional wind trend (m s^{-1}/decade)
0.20
0.15
0.10
0.05
0.00
−0.05
−0.10
−0.15
−0.20


OBS (ERA5)
CESM2-PI
PiC_UVnudge
PiC_UVnudge_LM
PInudge
PInudge-lessmelt
PiC_UVnudge_2006_2000
PiC_UVnudgenew
PiC_UVnudge_1988
2m air temperature (K)
264
262
260
258
256
254
1950 1955 1960 1965 1970 1975 1980 1985 1990 1995 2000 2005 2010 2015 2020
Year


CESM2-PI
PiC_UVnudge
PiC_UVnudge_LM
PInudge
PInudge-lessmelt
PiC_UVnudge_2006_2000
PiC_UVnudgenew
PiC_UVnudge_1988
Atlantic Meridional Overturning Circulation (Sv)
20
22
24
26
28
30
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
Year


CESM2-PI
PiC_UVnudge
PiC_UVnudge_LM
PInudge
PInudge-lessmelt
PiC_UVnudge_2006_2000
PiC_UVnudgenew
PiC_UVnudge_1988
Net TOA Imbalance (W/m2)
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
1950 1955 1960 1965 1970 1975 1980 1985 1990 1995 2000 2005 2010 2015 2020
Year

Future work:


New historical
CESM2+ERA5 ensemble
Single-forcing (e.g. greenhouse gases, aerosols, etc.)
+
Observed large-scale winds
−
CESM2+ERA5 ensemble from this work
Observed large-scale winds
Assessment of single-forcing contributions to observed trends