The Impacts of Observed Arctic Sea-ice Variability on the Cold Season Atmospheric Circulation in Large-ensemble AGCM Experiments

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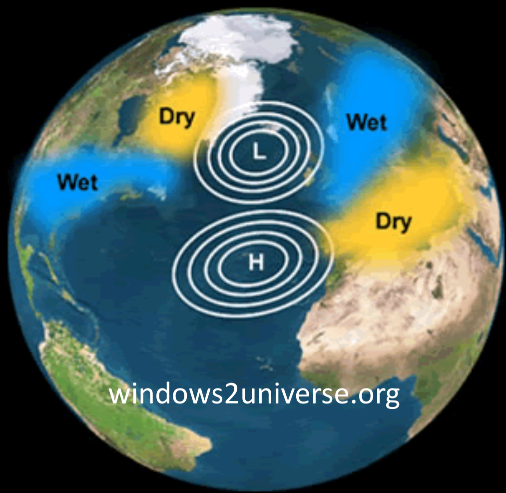
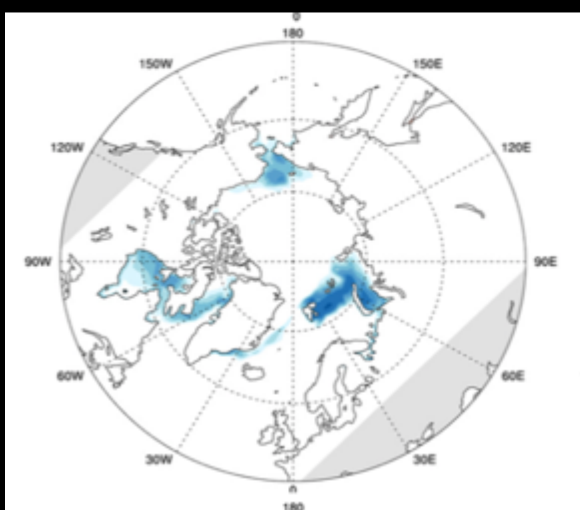
Thanks to 8 other groups: CNRS-LOCEAN, NERSC, DMI, MPI-M, UoS, CMCC, NLeSC, IAP

Observational Arctic sea ice-NAO linkage

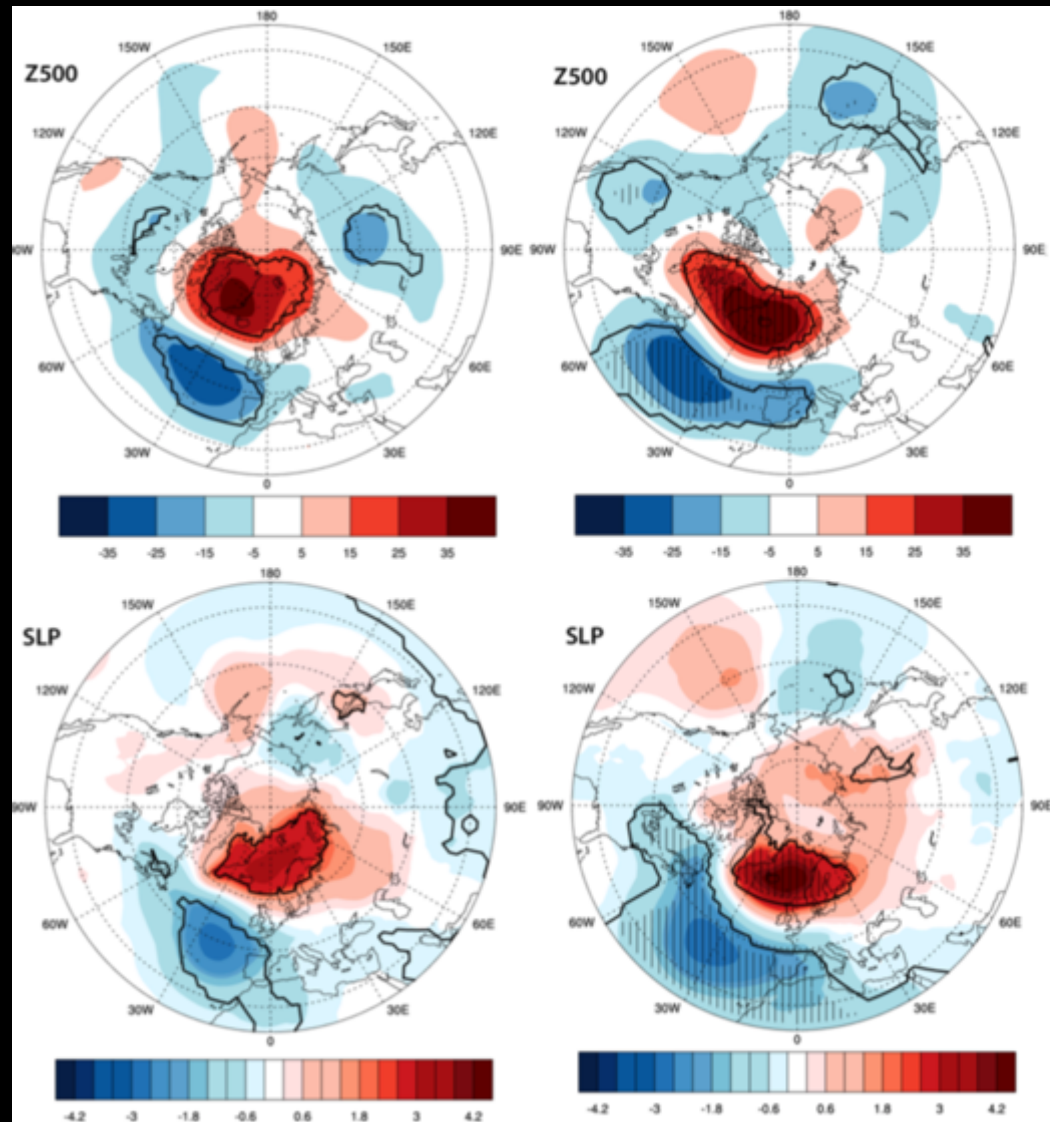
NAO



November SIC EOF1

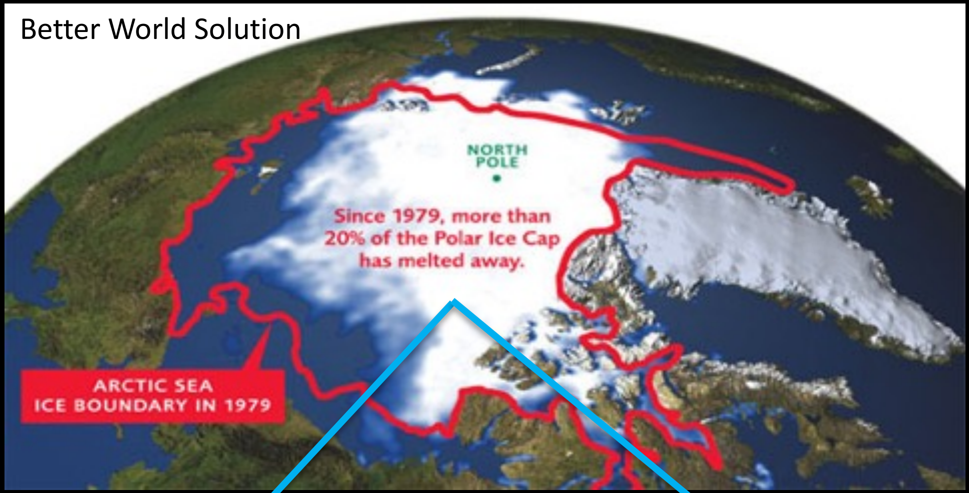


December January



Simon, Frankignoul, Kwon et al. (2020)

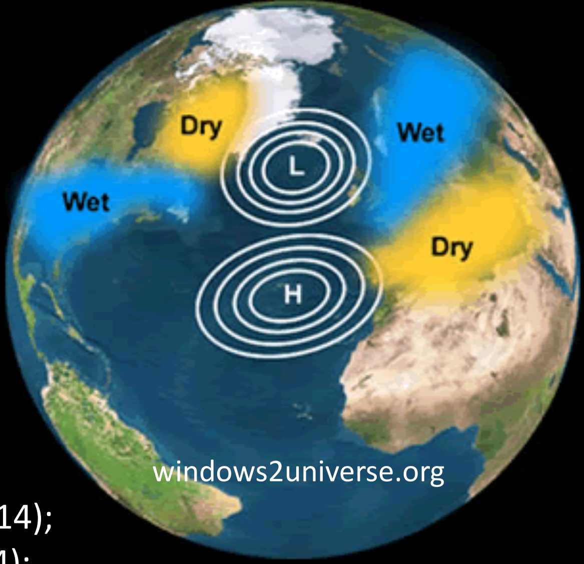
GCM is inconsistent in simulating North Atlantic Oscillation response

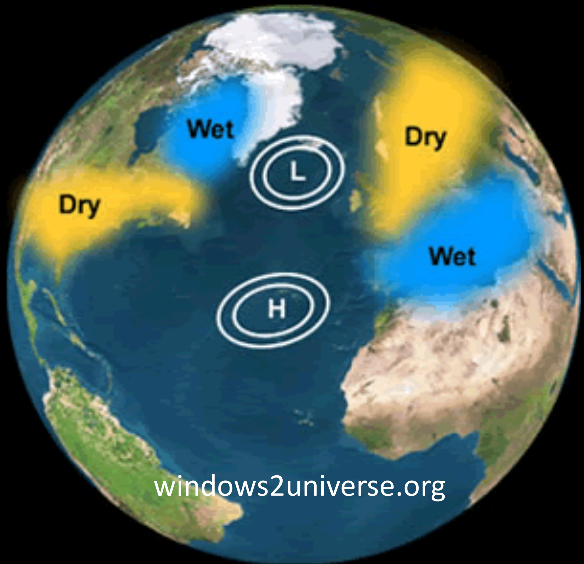


(+) NAO

?

(-) NAO





Cassano et al. (2014); Screen et al. (2014); many others

Peings & Magnusdottir (2014); many others

Coordinated Large-ensemble AGCM Experiments

9 AGCMs

165 members

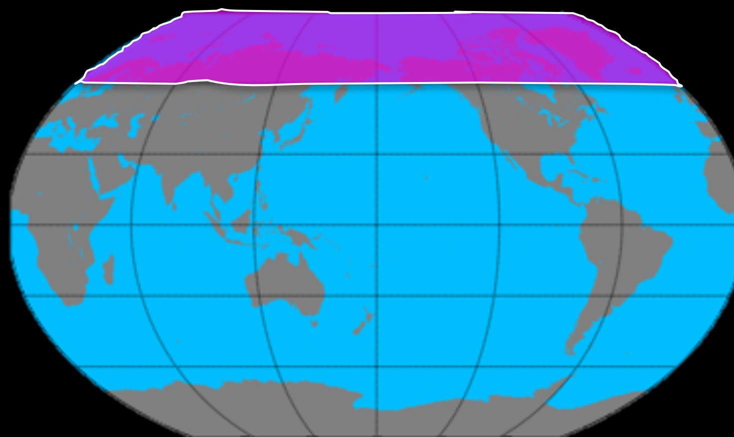
Model Name	Institution	Horizontal resolution (lat x lon)	# of vertical levels (top level)	# of ensemble members	Adjustment of SST/SIC	CMIP6 External Forcing used	Referecne
CESM2-WACCM6	WHOI-NCAR	0.94º x 1.25º (~100 km)	70 ($4.5x10^{-6}$ hPa)	30	Yes	CMIP6	Gettelman et al. (2019)
LMDZOR6	LOCEAN-IPSL	1.26º x 2.5º (~150 km)	79 (0.01 hPa)	30	Yes	HighResMIP	Hourdin et al. (2020)
NorEXM2-CAM6	NERSC	0.94º x 1.25º (~100 km)	32 (3.4 hPa)	30	Yes	CMIP6	Bentsen et al. (2013)
EC-Earth3-DMI	DMI	T255 (~80 km)	91 (0.01 hPa)	20	Yes	CMIP6	EC-Earth (2019) Thomas et al. (2019)
IAP4.1	IAP	1.4 º x1.4 º	30 (2.2hPa)	15	Yes	1979-2005: CMIP historical 2006-2013: CMIP5 RCP8.5	Sun et al. (2012)
CMCC-CM2-HR4	CMCC	0.9° x 1.25° (~100 km)	30 (2 hPa)	10	No	HighResMIP	Cherchi et al. (2018)
EC-Earth3-NLeSC	NLeSC	T511 (~40km)	91 (0.01 hPa)	10	Yes	HighResMIP	EC-Earth (2019) Thomas et al. (2019)
ECHAM6.3	MPI-M	T127 (~100km)	95 (0.01hPa)	10	Yes	CMIP6	Stevens et.al.(2013) Mueller et. al. (2018)
HadGEM3-GC3.1	UoS	0.83º x 0.55º (~60 km)	85 (85 km)	10	No	HighResMIP	Walters et al. (2017)

BLUE ACTION

Coordinated Large-ensemble AGCM Experiments

Time-varying Arctic sea ice and global SST and GHG forcings (1979-2014)

EXP1/**ALL**
(All forcing)



Climatological Arctic sea ice and time-varying global SST and GHG forcings

EXP2/**SIC**$_{clim}$
(Forcing without time-varying Arctic sea-ice)

Hadley SST and SIC

BLUE ACTION

Scientific Questions

1. Can AGCMs simulate the Arctic sea-ice impacts on large-scale atmospheric circulation, in the Northern Hemisphere cold season (OND and JFM), identified in reanalysis datasets?

2. What is the role of internal atmospheric variability?

3. How large is the Arctic sea-ice forced atmospheric circulation?

1979-2014 long-term Trend

Interannual variability

Scientific Questions

1. Can AGCMs simulate the Arctic sea-ice impacts on large-scale atmospheric circulation, in the Northern Hemisphere cold season (OND and JFM), identified in reanalysis datasets?

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1979-2014 long-term Trend

Interannual variability

Basic Assumptions

1. Forced component can be separated from internal variability by taking multi-model ensemble mean (MMM, $\overline{(X)}$) over 165 members.

2. Atmospheric circulation response to Arctic sea-ice variability is sufficiently linear (additive).

- $\overline{\mathrm{ALL}}$: component forced by SIC, SST, GHG, radiative forcings

- $\overline{\mathrm{SIC_{clim}}}$: component forced by ~~SIC~~, SST, GHG, radiative forcings

- Arctic sea-ice forced component can be represented as

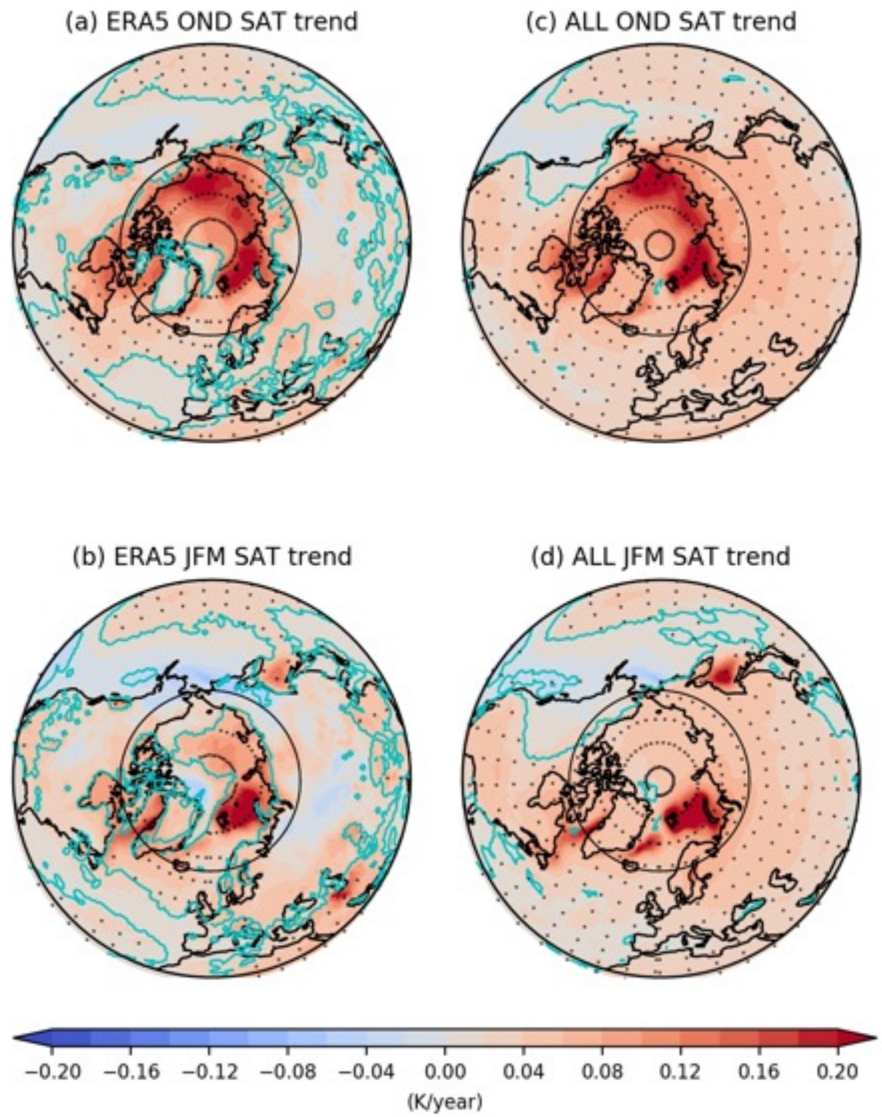
$\overline{\mathrm{ALL}}$ minus $\overline{\mathrm{SIC_{clim}}}$
(SI MMM)

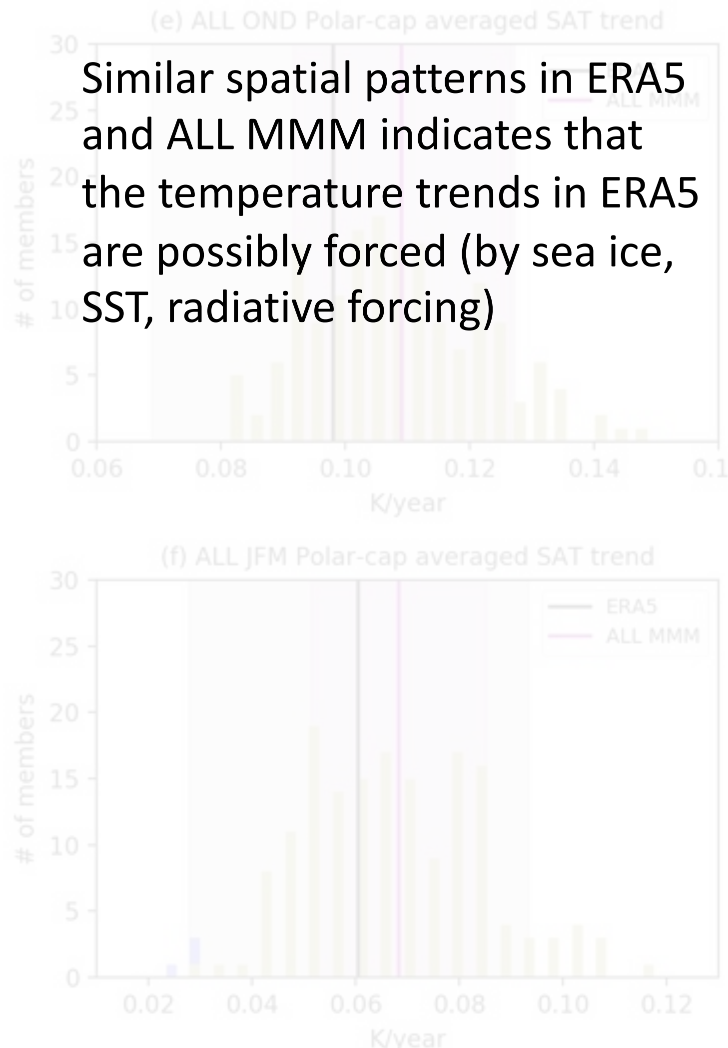
Comparison of surface air temperature trends in ALL MMM and ERA5

ERA5 reanalysis | ALL MMM

OND

JFM





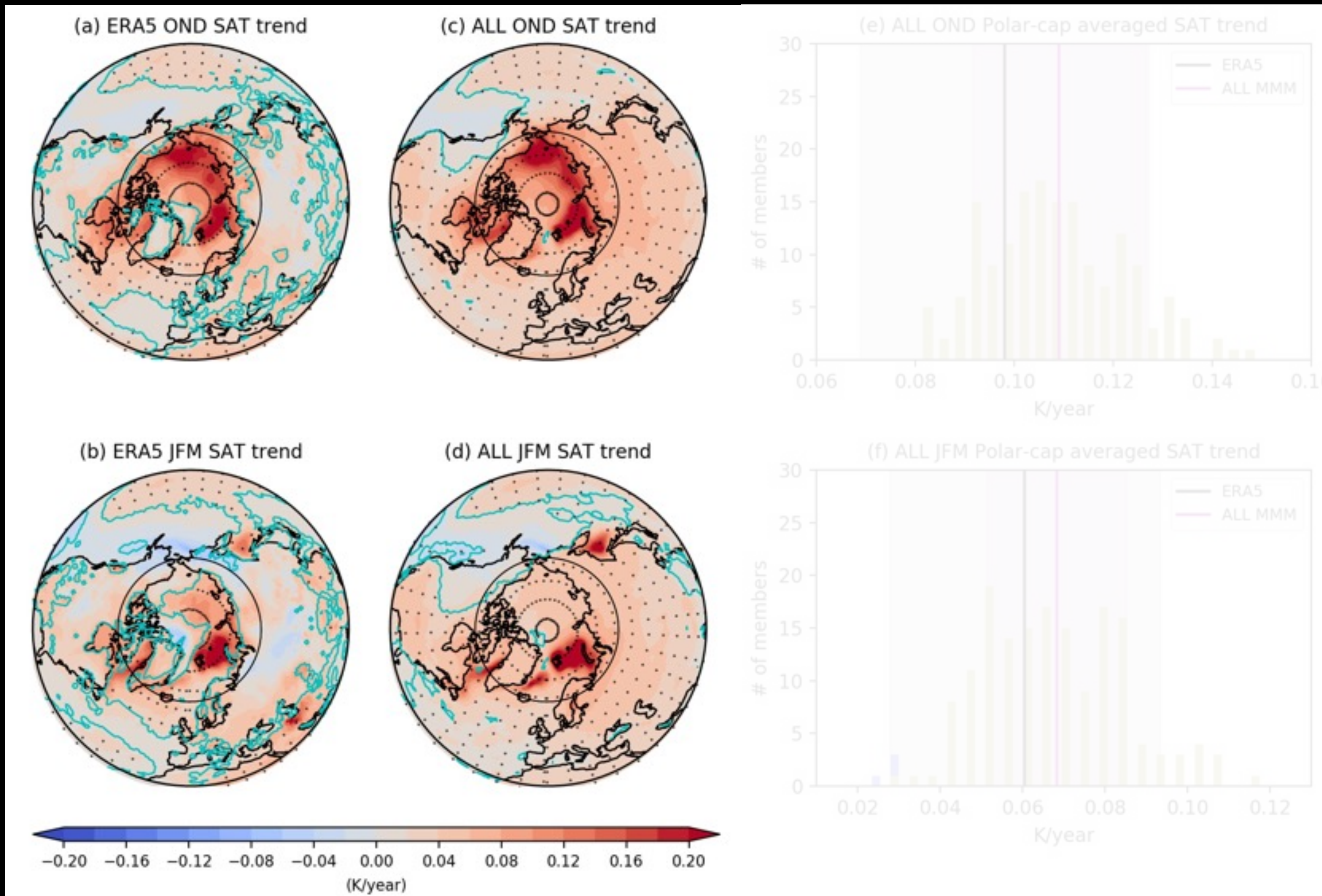
Similar spatial patterns in ERA5 and ALL MMM indicates that the temperature trends in ERA5 are possibly forced (by sea ice, SST, radiative forcing)

Comparison of surface air temperature trends in ALL MMM and ERA5

ERA5 reanalysis | ALL MMM

OND

JFM

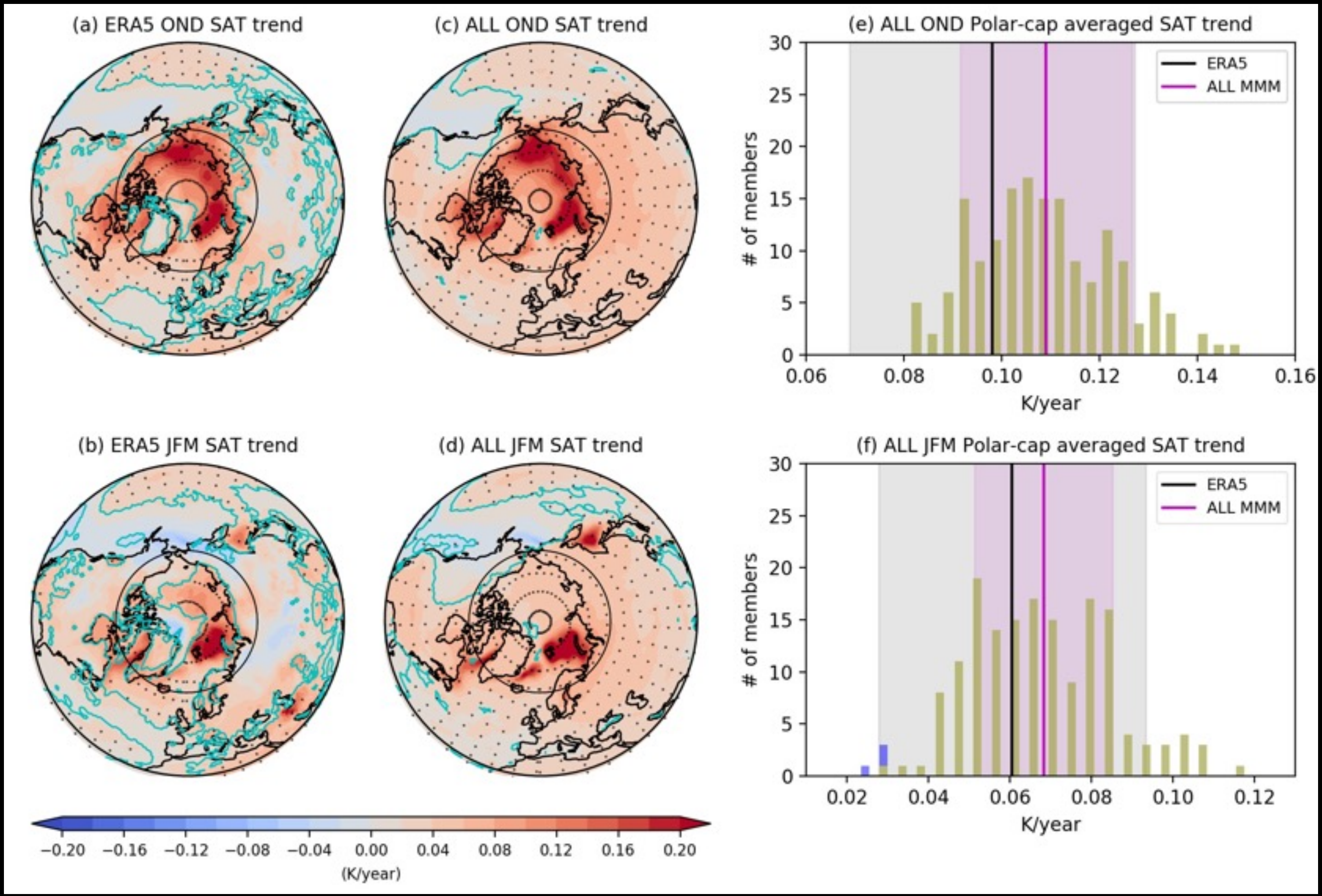


Comparison of surface air temperature trends in ALL MMM and ERA5

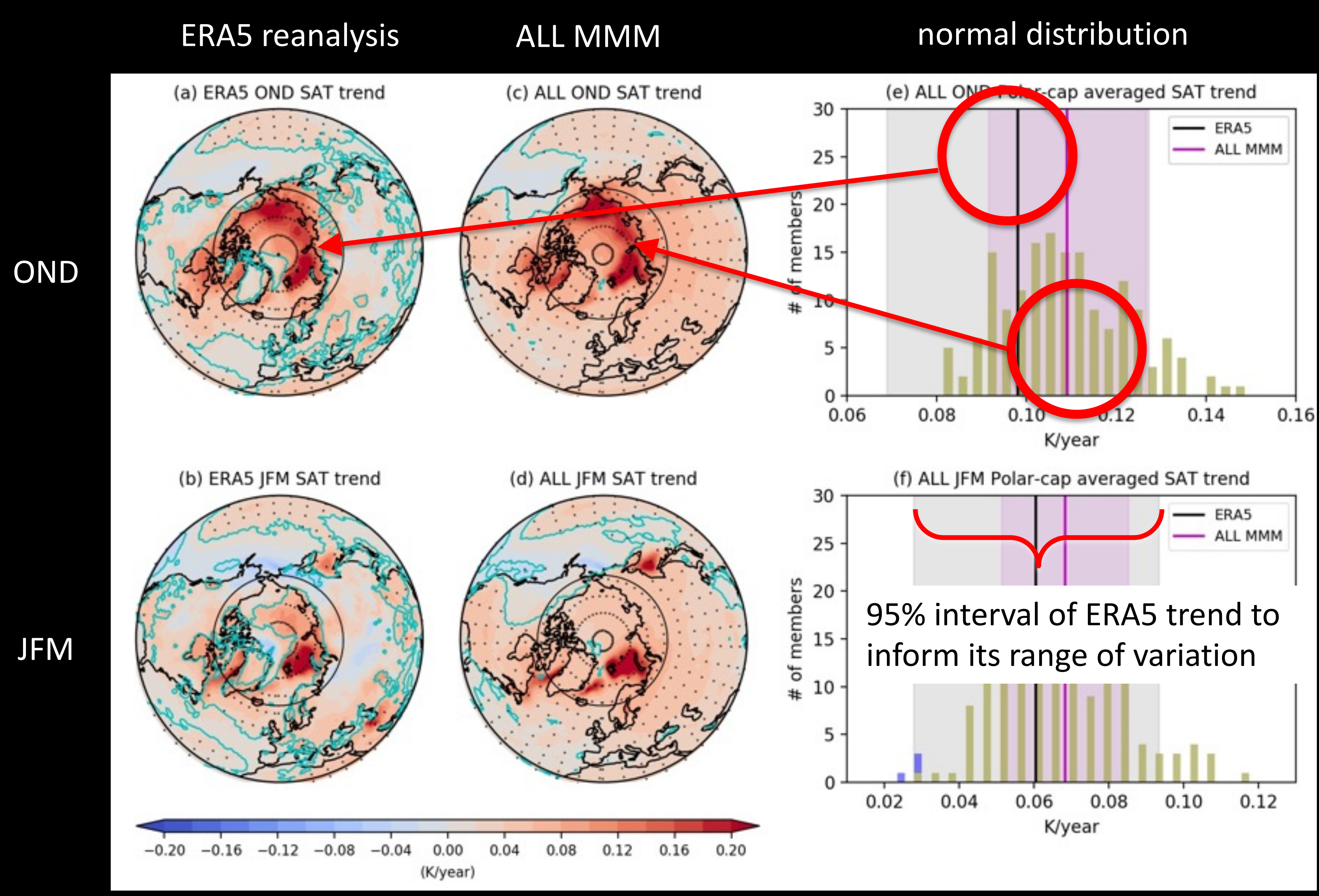
ERA5 reanalysis | ALL MMM | normal distribution

OND

JFM



Comparison of surface air temperature trends in ALL MMM and ERA5



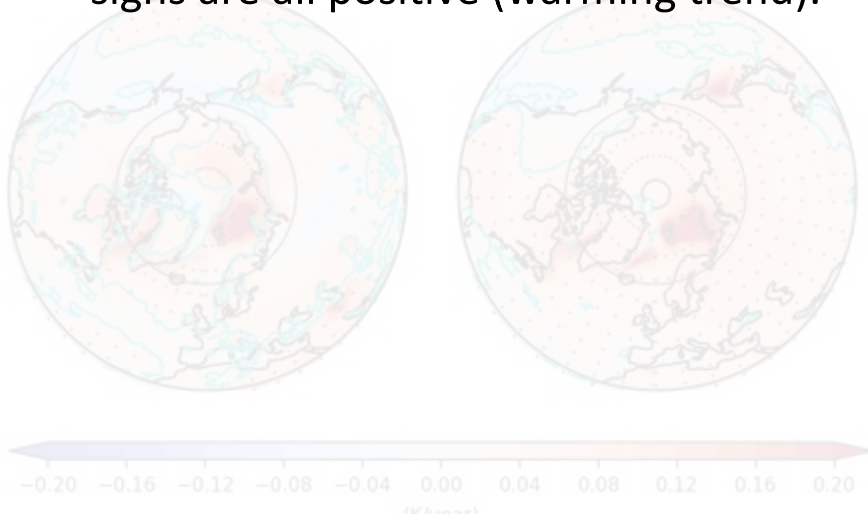
Comparison of surface air temperature trends in ALL MMM and ERA5

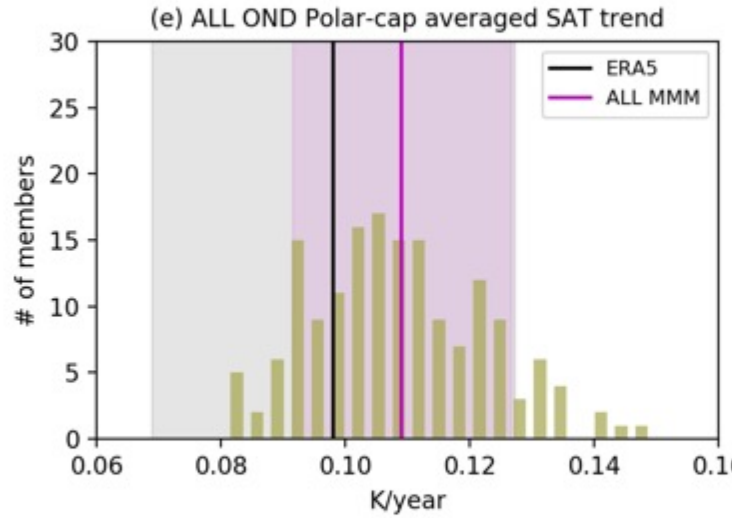
ERA5 reanalysis | ALL MMM | normal distribution

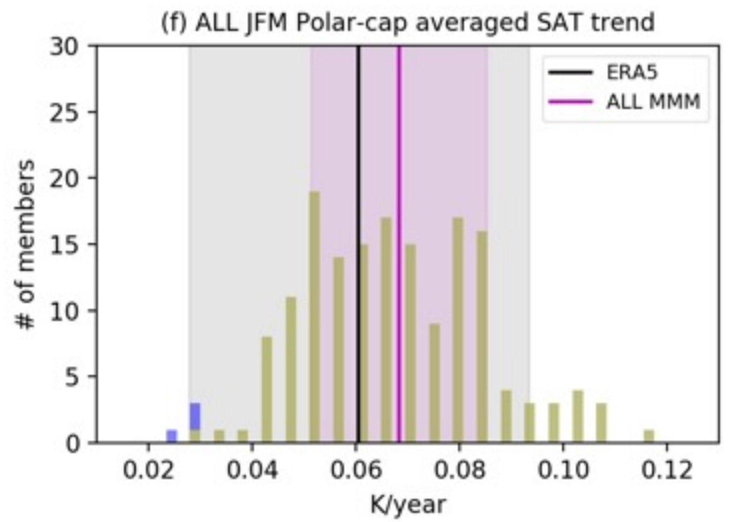
OND

JFM

1. Range of ERA5 is similar to model distribution spread
   → large internal variability contribution.
2. Range difference between black and magenta shadings
   → reduction of internal variability
3. Despite effects of internal variability, the signs are all positive (warming trend).





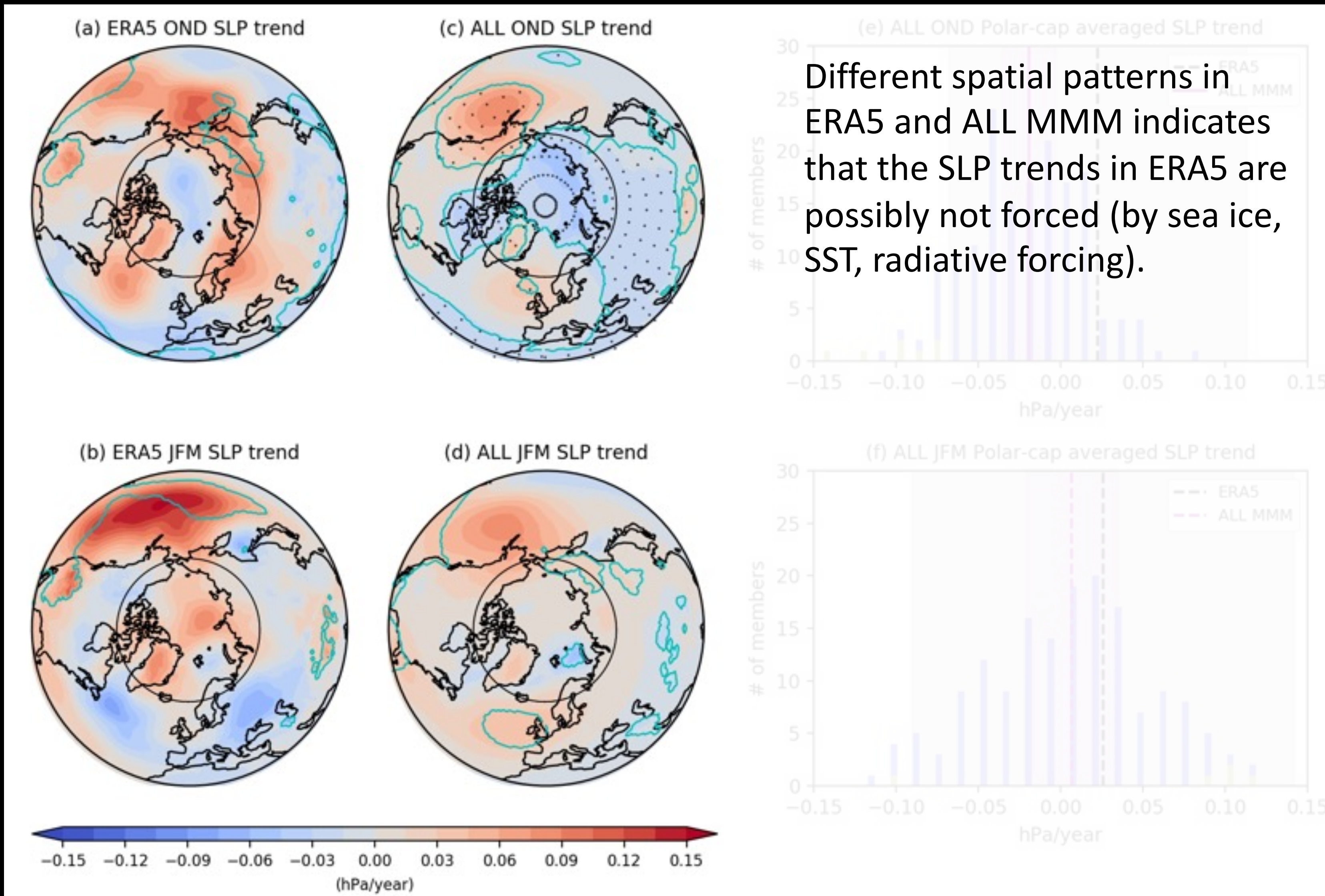


Comparison of sea-level pressure trends in ALL MMM and ERA5

ERA5 reanalysis ALL MMM

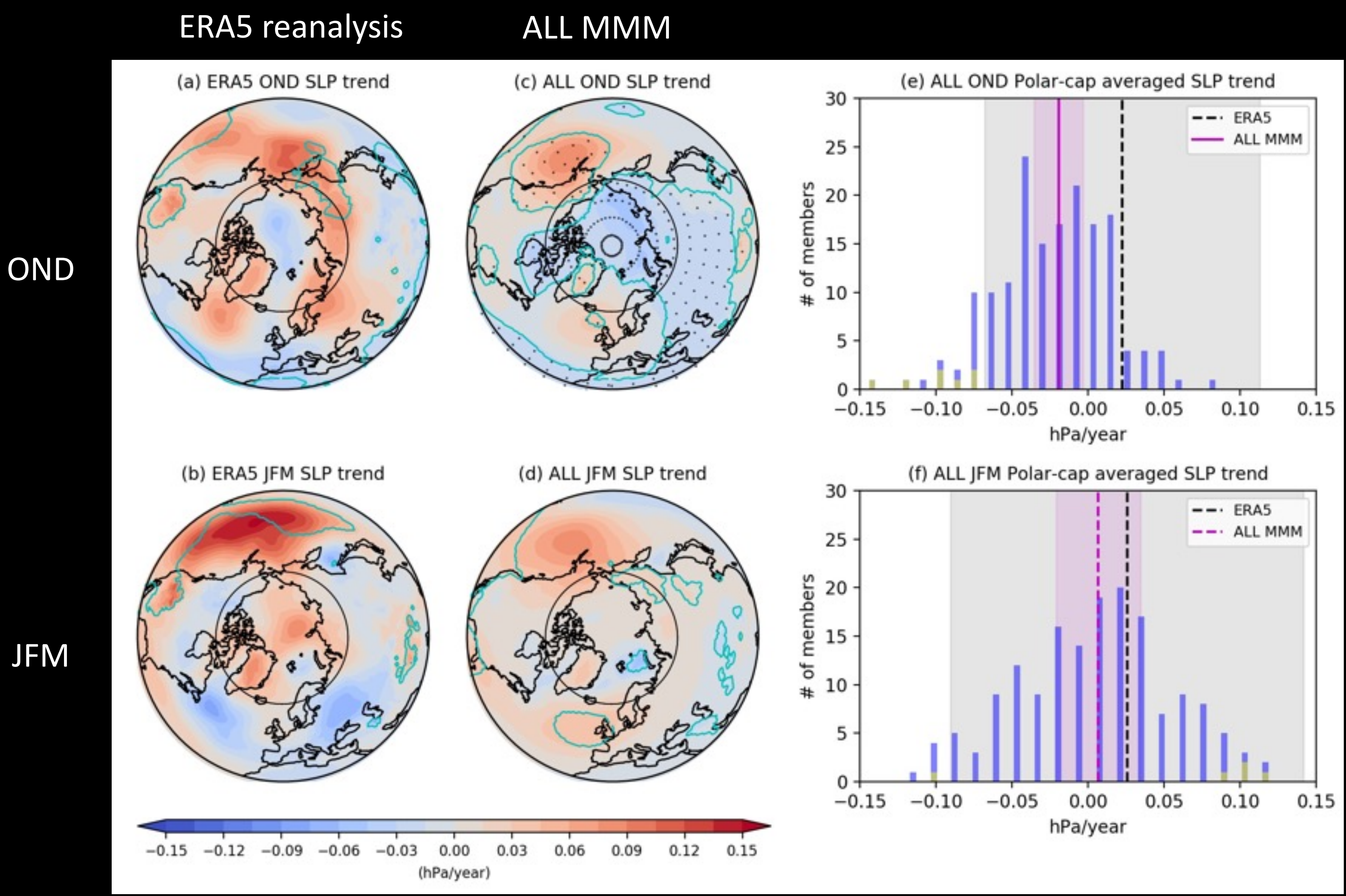
OND

JFM



Different spatial patterns in ERA5 and ALL MMM indicates that the SLP trends in ERA5 are possibly not forced (by sea ice, SST, radiative forcing).

Comparison of sea-level pressure trends in ALL MMM and ERA5



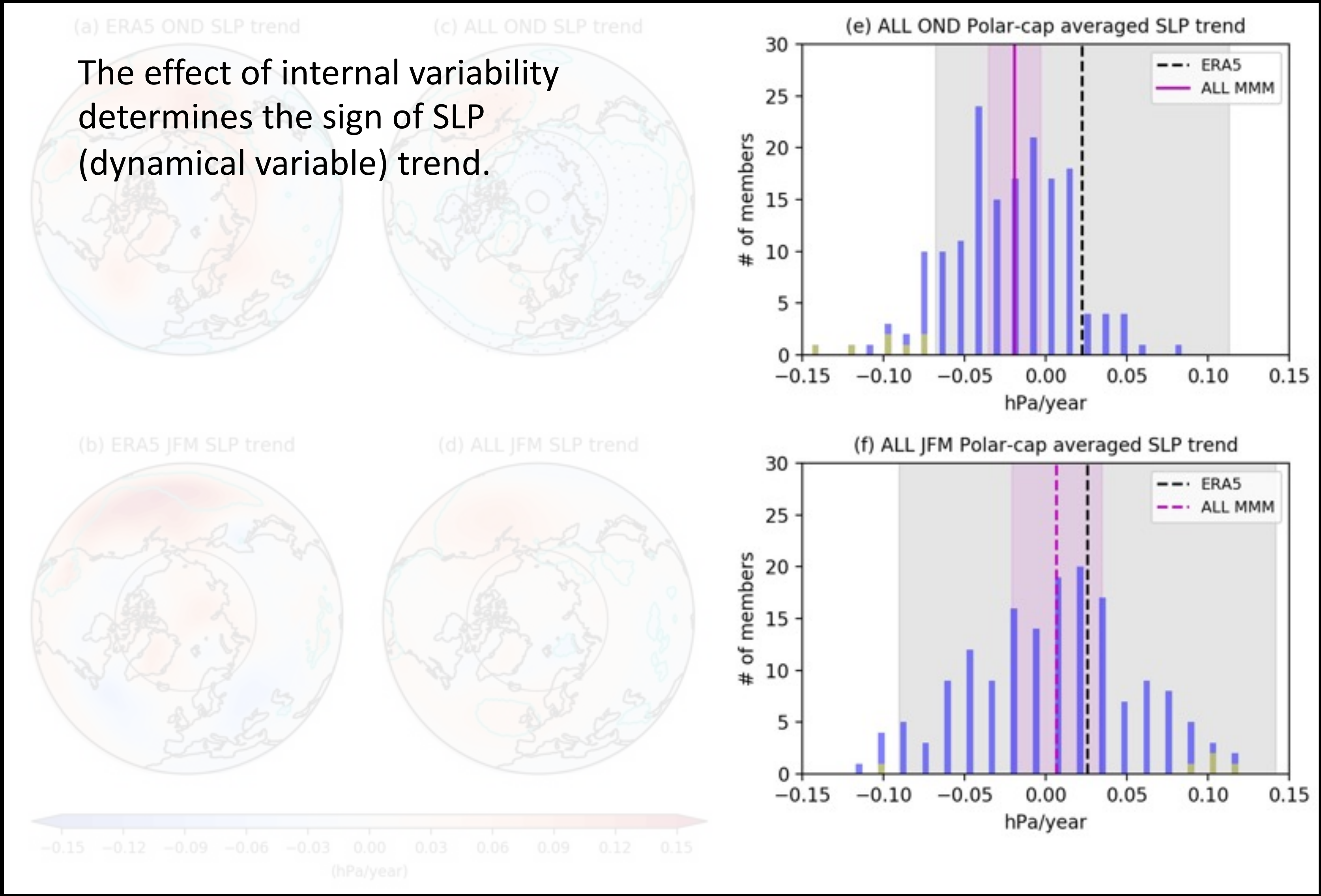
Comparison of sea-level pressure trends in ALL MMM and ERA5

ERA5 reanalysis ALL MMM

OND

JFM

The effect of internal variability determines the sign of SLP (dynamical variable) trend.



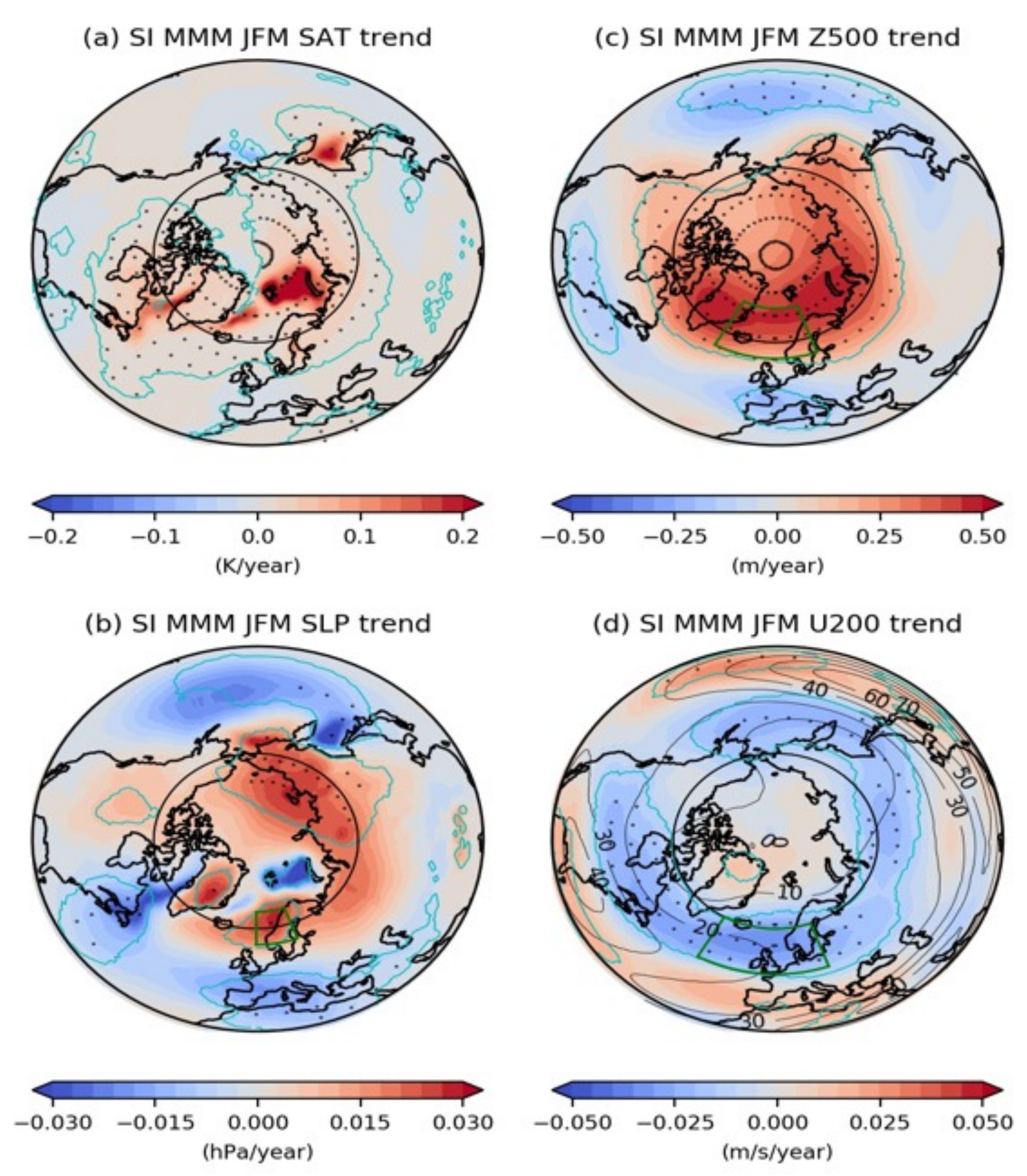
Arctic sea ice-forced (SI MMM) trends in surface and mid-troposphere

SI MMM = $\overline{\mathbf{ALL}}$ minus $\overline{\mathbf{SIC_{clim}}}$

Arctic sea ice-forced (SI MMM) trends in surface and mid-troposphere

strong localized warming

localized low SLP remote high SLP



-AO/-NAO pattern

weakened/ southward midlatitude jet

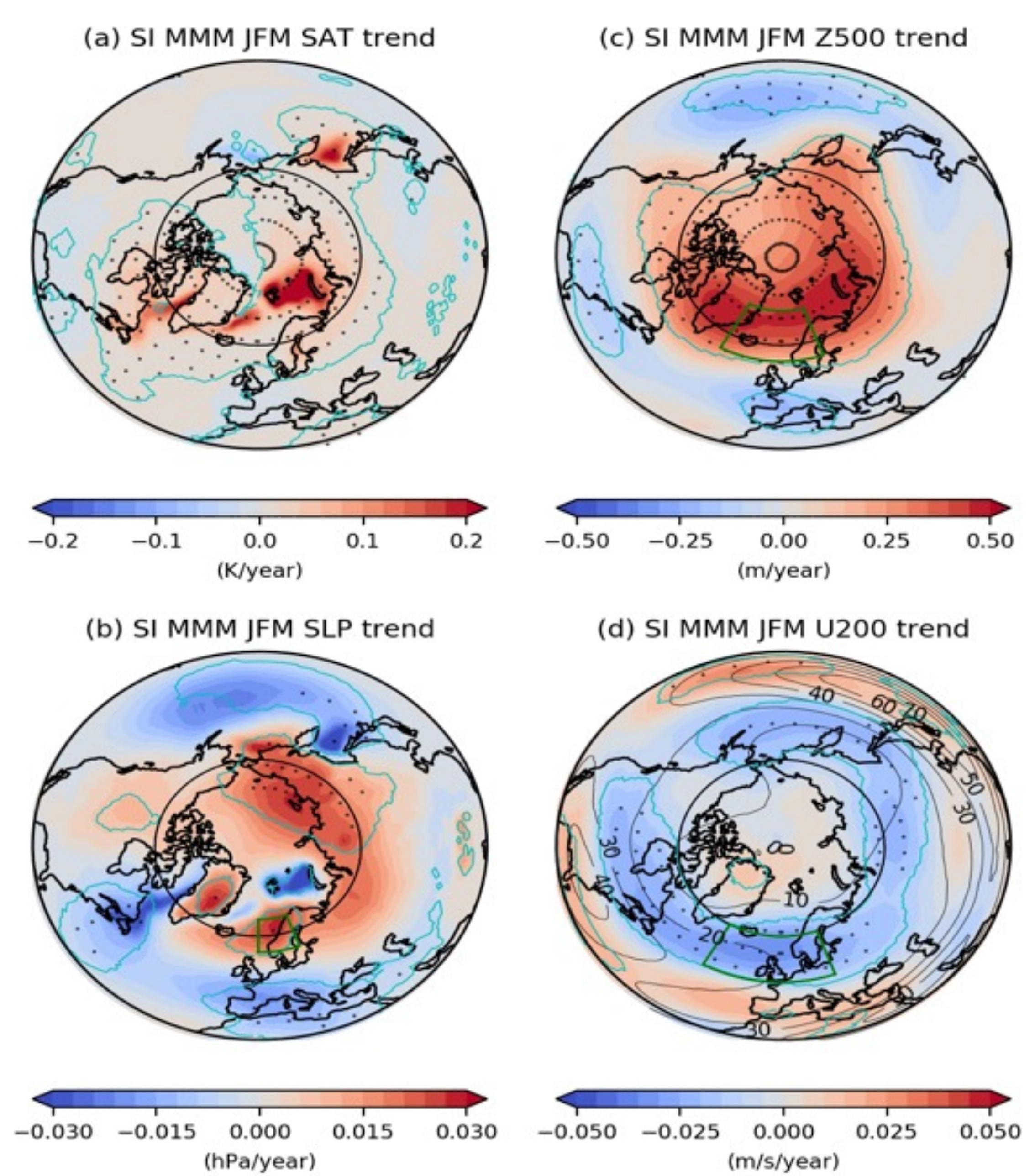
Arctic sea ice-forced (SI MMM) trends in surface and mid-troposphere

strong localized warming

localized low SLP
remote high SLP

0.21±0.18 (5±2) hPa/decade

Observational estimates from Simon et al. (2020)



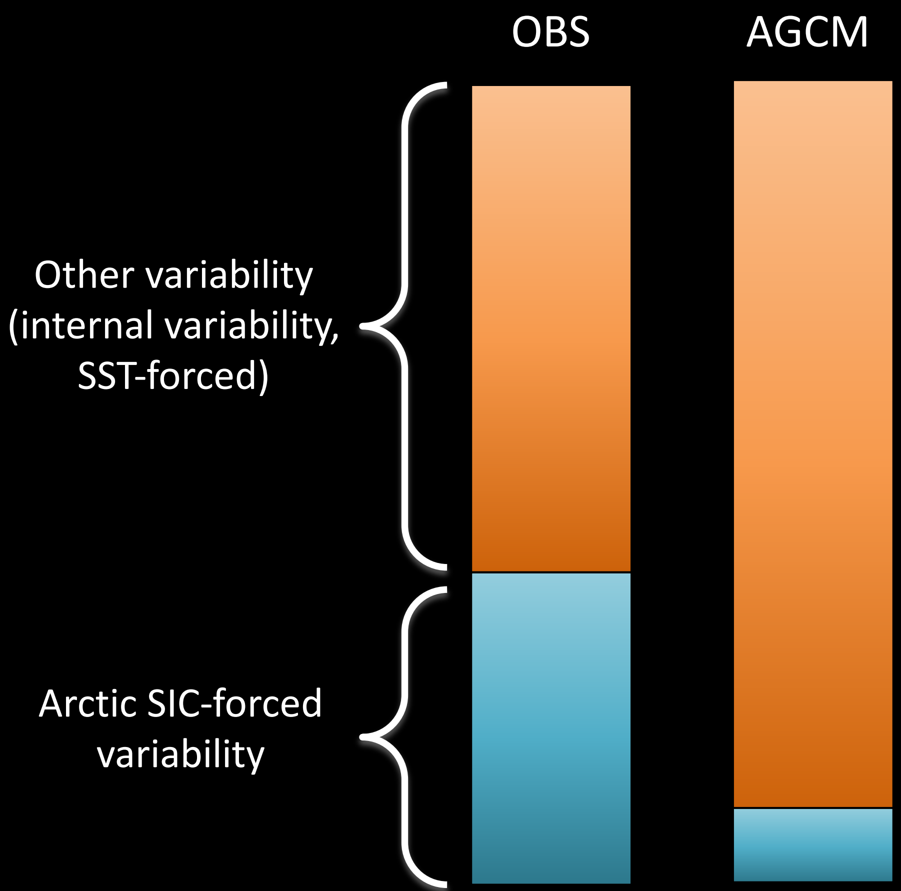
-AO/-NAO pattern

3.7±2.0 (60±20) m/decade

weakened/ southward midlatitude jet

Summary

- Arctic warming trends are reasonably simulated in AGCMs, but not for dynamical variables (large internal variability).
- The Arctic SIC-forced trend responses (–NAO) have smaller magnitudes compared to observational estimates.
- AGCMs underestimate the SIC-SLP co-variability at interannual timescale.



Please email me if you have questions: **yliang@whoi.edu**
Thank you!

Scatter plot for *SC* against *R* of MCA on Dec SLP-Mar SLP in ALL