Impacts of Arctic Sea Ice on Cold Season Atmospheric Trends Estimated from Observations and a Multi-model Large Ensemble

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A. Introduction

To examine the atmospheric responses to Arctic sea ice variability in the Northern Hemisphere cold season (from October to the following March), we use a coordinated sets of large-ensemble experiments of nine atmospheric general circulation models (**AGCMs**) forced during the **1979–2014 period**. The simulations reproduce the near-surface temperature trends in reanalysis data, with similar amplitude, and their multi-model ensemble mean shows decreasing sea level pressure over much of the polar cap and Eurasia in boreal autumn. We also find that the effects of Arctic sea ice loss explain a large portion of the Arctic warming trends in the lower troposphere and drive a small but statistically significant weakening of the wintertime Arctic Oscillation. We also take into account the impacts of interdecadal Pacific variability (**IPV**) and Atlantic multidecadal variability (**AMV**) on the trends.

B. AGCM Simulations & Reanalysis Data

Model name	Institution	Horizontal resolution (lat × lon)	No. of vertical levels (top level)	No. of ensemble members	Adjustment of SST/SIC	CMIP6 external forcing	Referer
CESM2-WACCM6	WHOI–NCAR	0.94° × 1.25° (~100 km)	70 (4.5×10^{-6} hPa)	30	Yes	CMIP6	Gettelman et a
LMDZOR6	LOCEAN–IPSL	1.26° × 2.5° (~150 km)	79 (0.01 hPa)	30	Yes	HighResMIP	Hourdin et al.
NorESM2-CAM6	NERSC	0.94° × 1.25° (~100 km)	32 (3.4 hPa)	30	Yes	CMIP6	Bentsen et al. Seland et al
EC-Earth3-DMI	DMI	T255 (~80 km)	91 (0.01 hPa)	20	Yes	CMIP6	Döscher et al.
IAP4.1	IAP	1.4° × 1.4°	30 (2.2 hPa)	15	Yes	1979–2005: CMIP5 historical; 2006–13: CMIP5 RCP8.5	Sun et al. (201
CMCC-CM2-HR4	CMCC	0.9° × 1.25° (~100 km)	30 (2 hPa)	10	No	HighResMIP	Cherchi et al.
EC-Earth3-NLeSC	NLeSC	T511 (~40 km)	91 (0.01 hPa)	10	Yes	HighResMIP	Döscher et al.
ECHAM6.3	MPI-M	T127 (~100 km)	95 (0.01 hPa)	10	Yes	CMIP6	Stevens et al. Müller et al
HadGEM3-GC3.1	UoS	0.83° × 0.55° (~60 km)	85 (85 km)	10	No	HighResMIP	Walters et al.

9 models **total 165 members**

AGCM Experiment 1 (EXP1, ALL):
Sea-surface temperature and sea-ice concentration are time-varying.

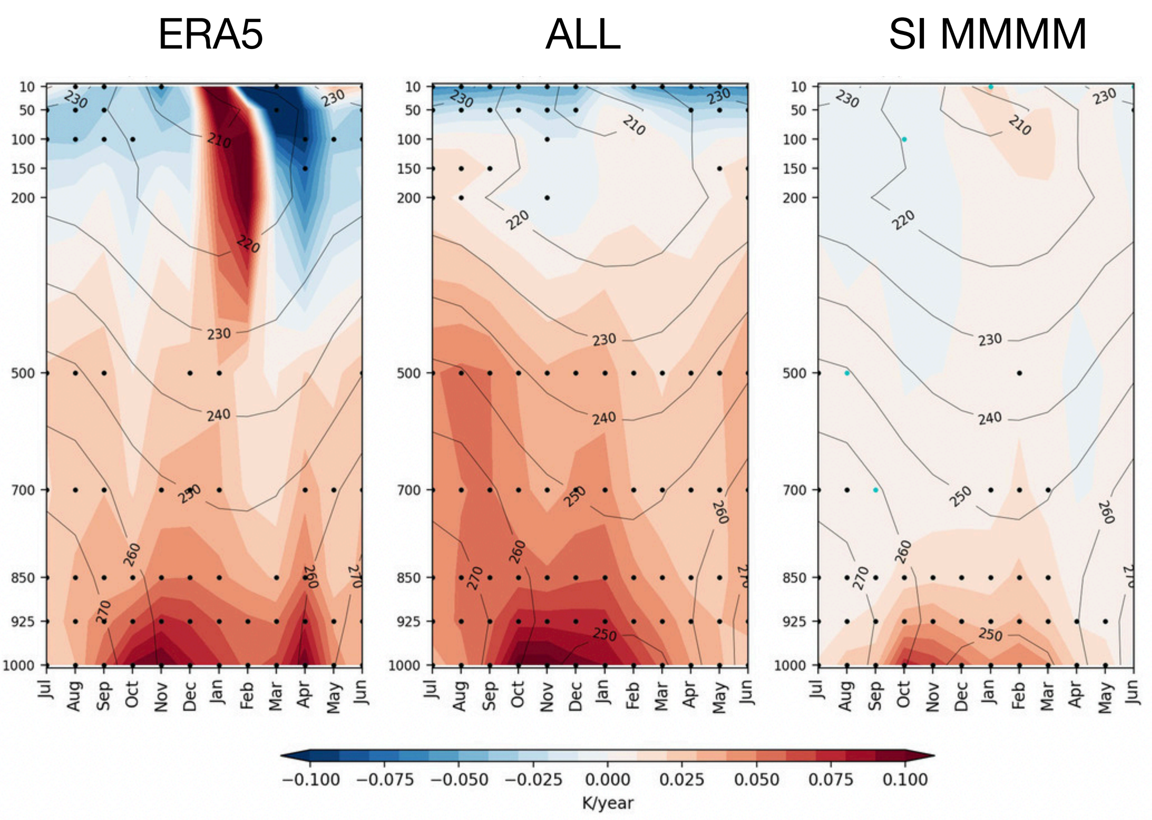
AGCM Experiment 2 (EXP2):
Sea-surface temperature is time-varying but climatological sea-ice concentration is prescribed.

*the Met Office Hadley Centre Sea Ice and SST version 2.2.0.0 dataset

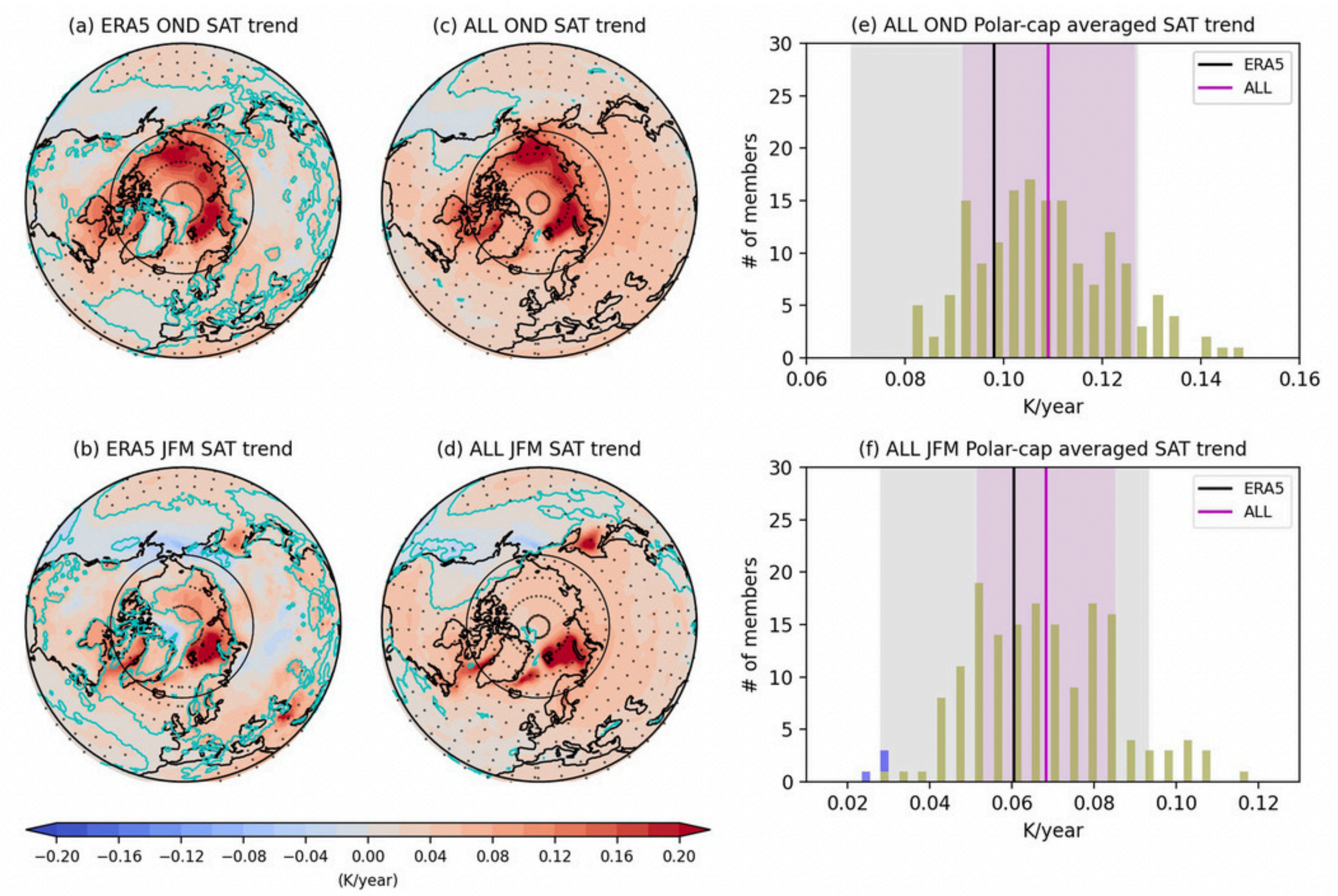
Sea-ice impacts (SI MMMM):
multi-model mean of EXP1
minus
multi-model mean of EXP2

Reanalysis data:
1. ERA5
2. ERA-Interm
3. JRA-55
4. MERRA-2
5. NCAR-DOE

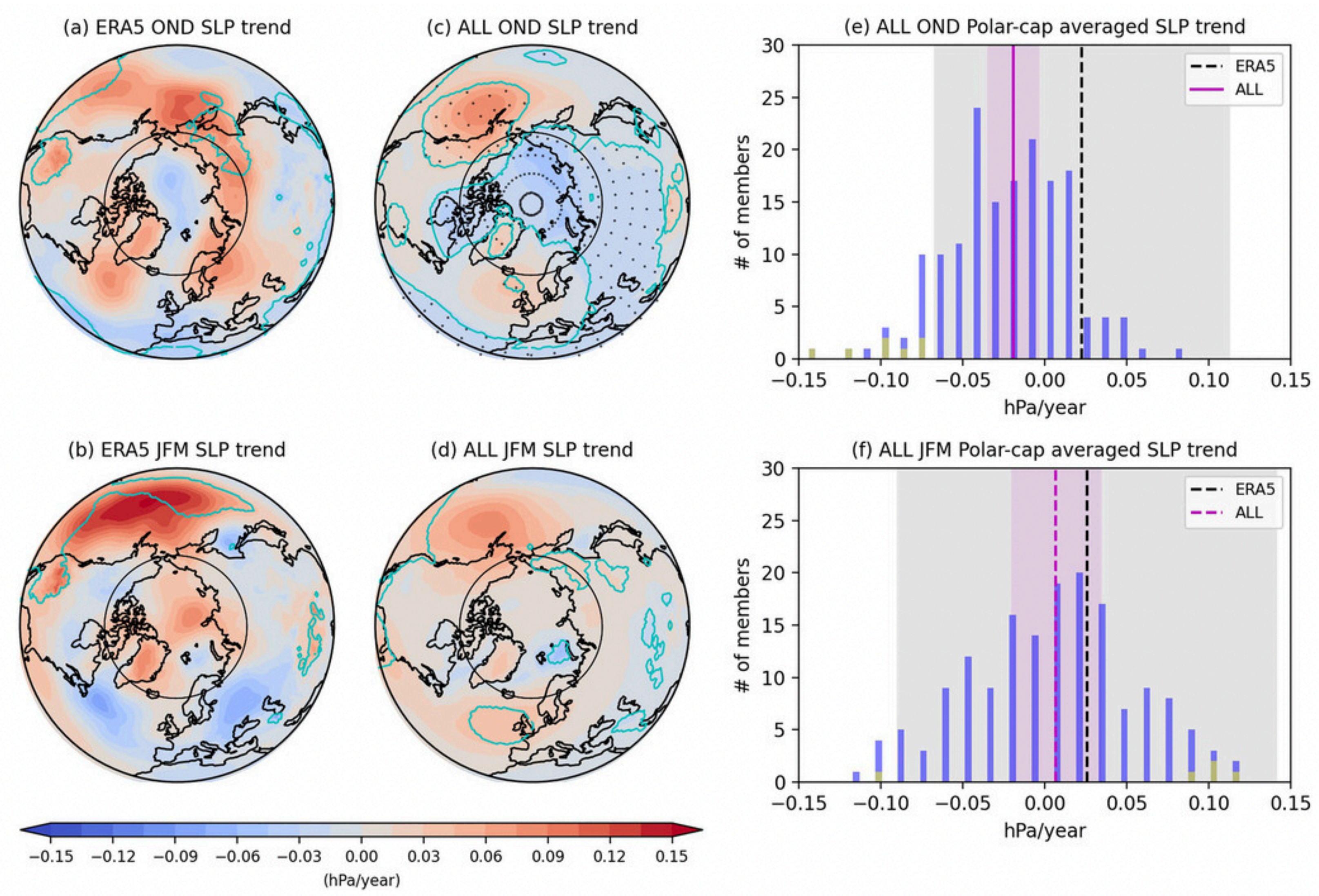
C. Linear Trends of Arctic-averaged Temperature



D. Linear Trends of Arctic Surface Temperature



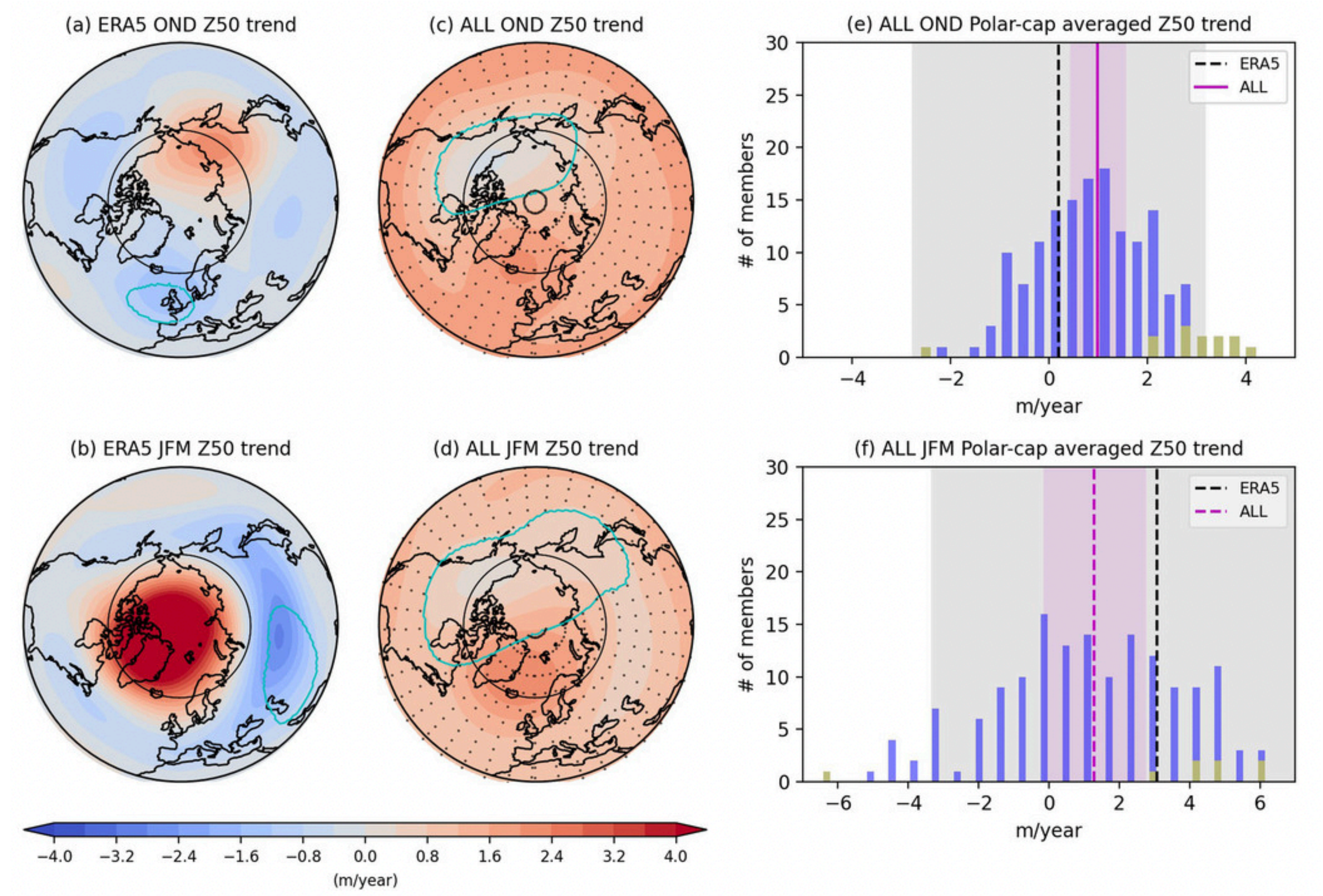
E. Linear Trends of Arctic Sea Level Pressure



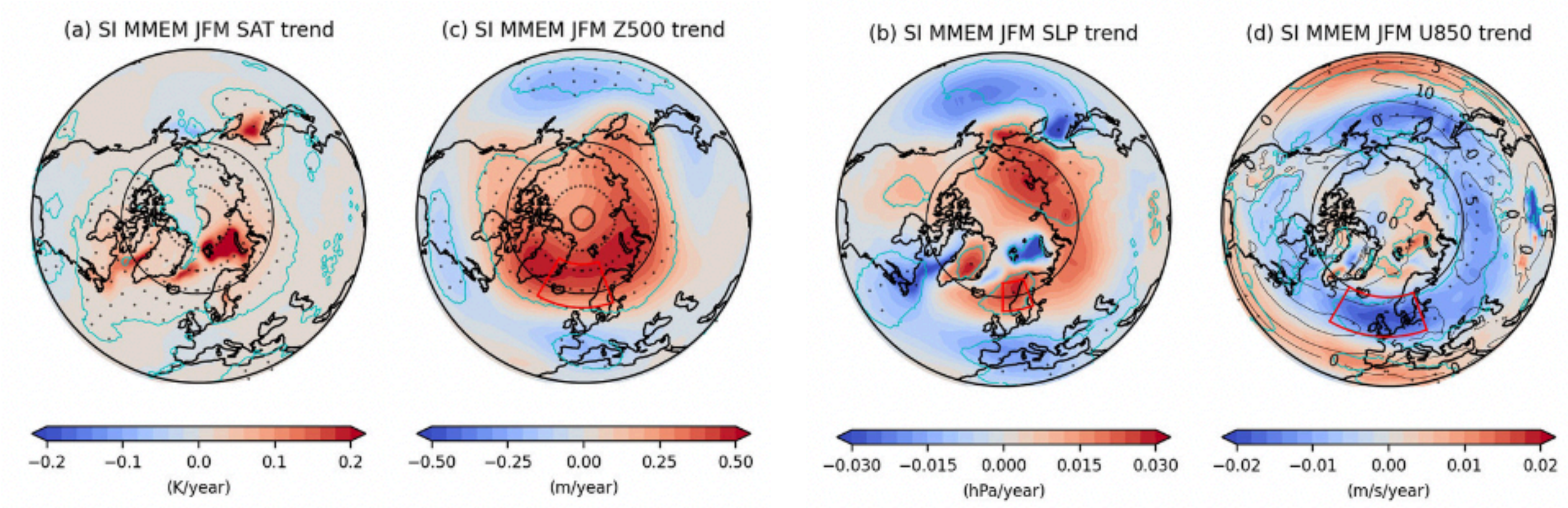
I. Conclusions

- The results suggest that the sea ice impacts on trends simulated by AGCMs could be **underestimated** and modulated by variability at longer timescales.
- Caution is needed because internal atmospheric variability may have affected the observed relationship.
- IPV and AMV intensify the warming when transitioning to positive phases and dampen the warming when transitioning to negative phases.

F. Linear Trends of Arctic Stratospheric Height



G. Linear Trends of Arctic Sea Ice Impacts



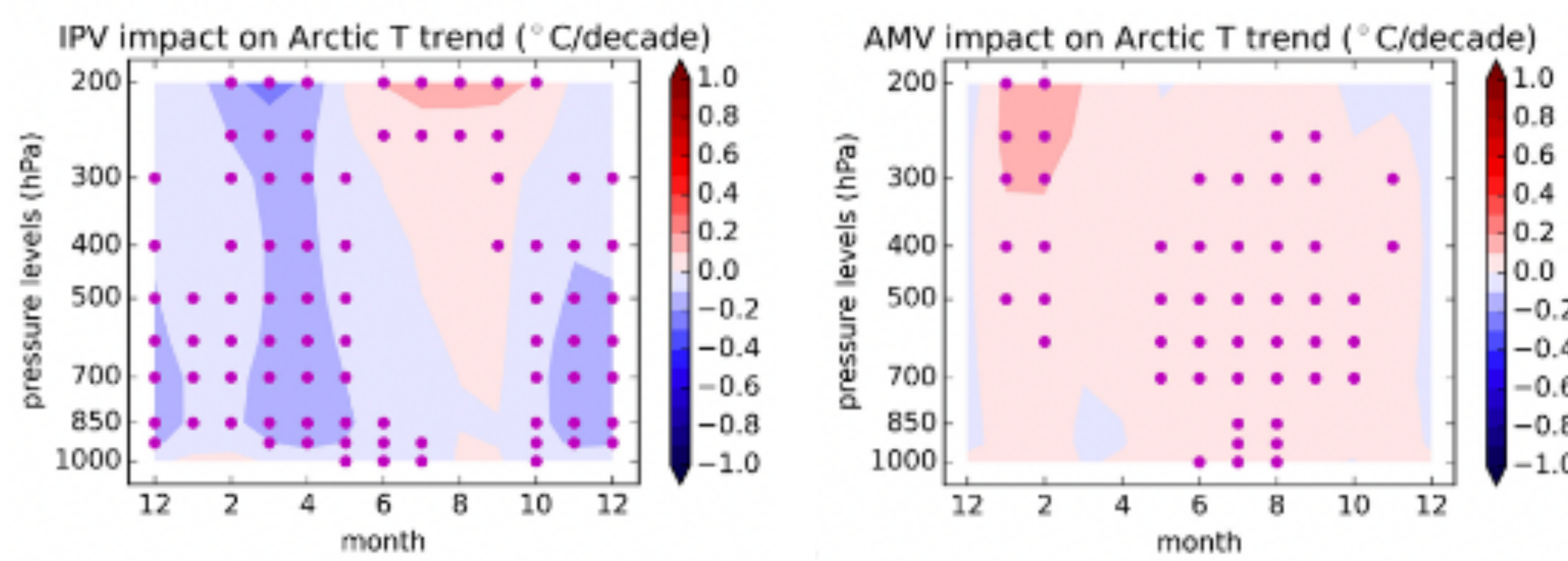
Large localized SAT trends

Negative northern annular mode (NAM) trends

- Negative North Atlantic Oscillation (NAO) trends
- Enhanced SLP trends in eastern Siberia.

Reduced zonal winds in midlatitudes

H. IPV and AMV impacts on Arctic Temperature Trend



J. Reference

Liang, Y.-C. And Coauthors (2021), Impacts of Arctic sea ice on cold season atmospheric variability and trends estimated from observations and a multimodel large ensemble, Journal of Climate, 24, 8419-8443.