Observed and Modelling Evidences of Significant Impacts of Antarctic Dipole Sea Ice Anomalies on the Antarctic Oscillation

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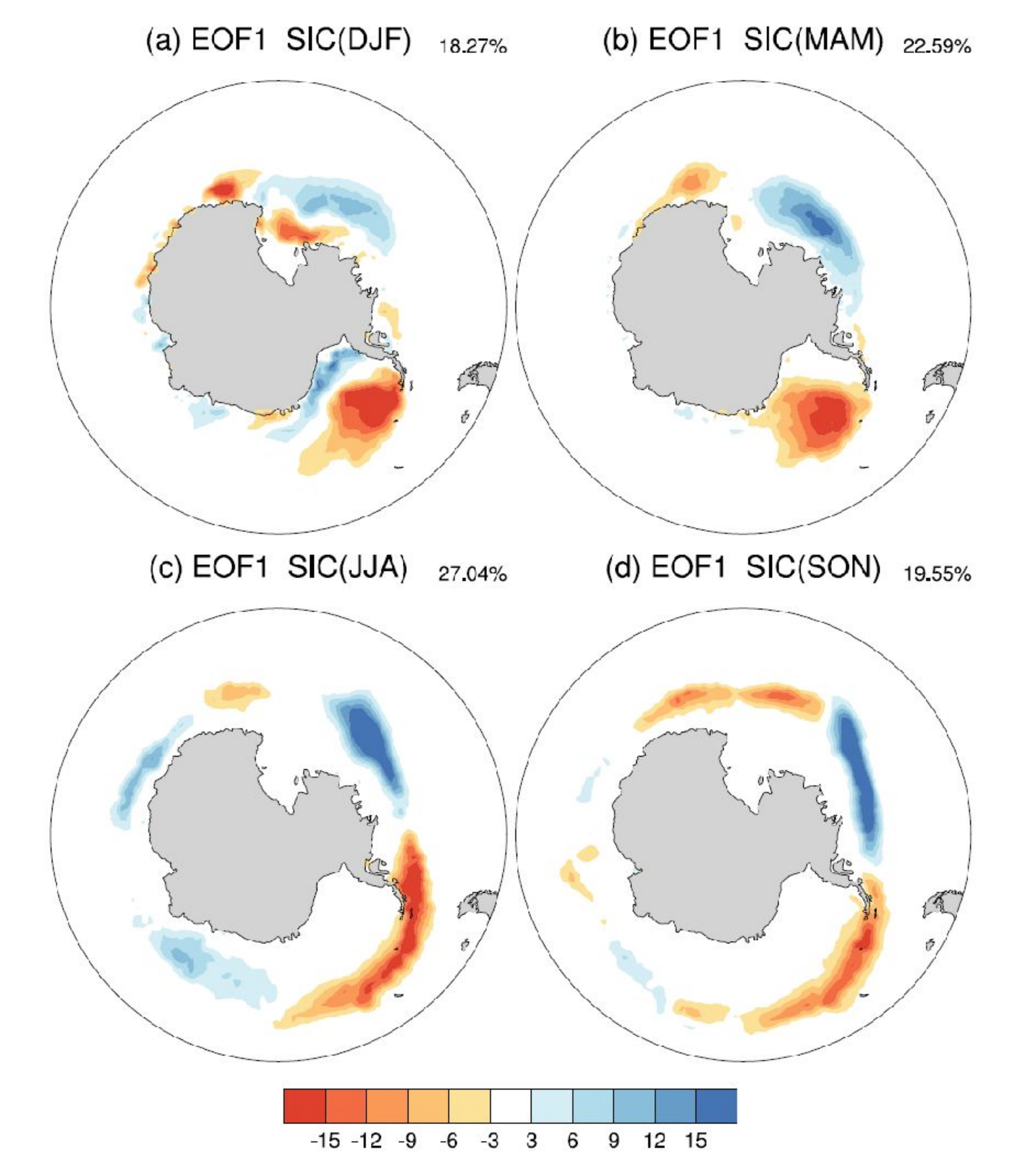
Introduction

- Unlike the Arctic, relatively few observational studies have been published about the atmospheric responses to Antarctic sea ice changes.

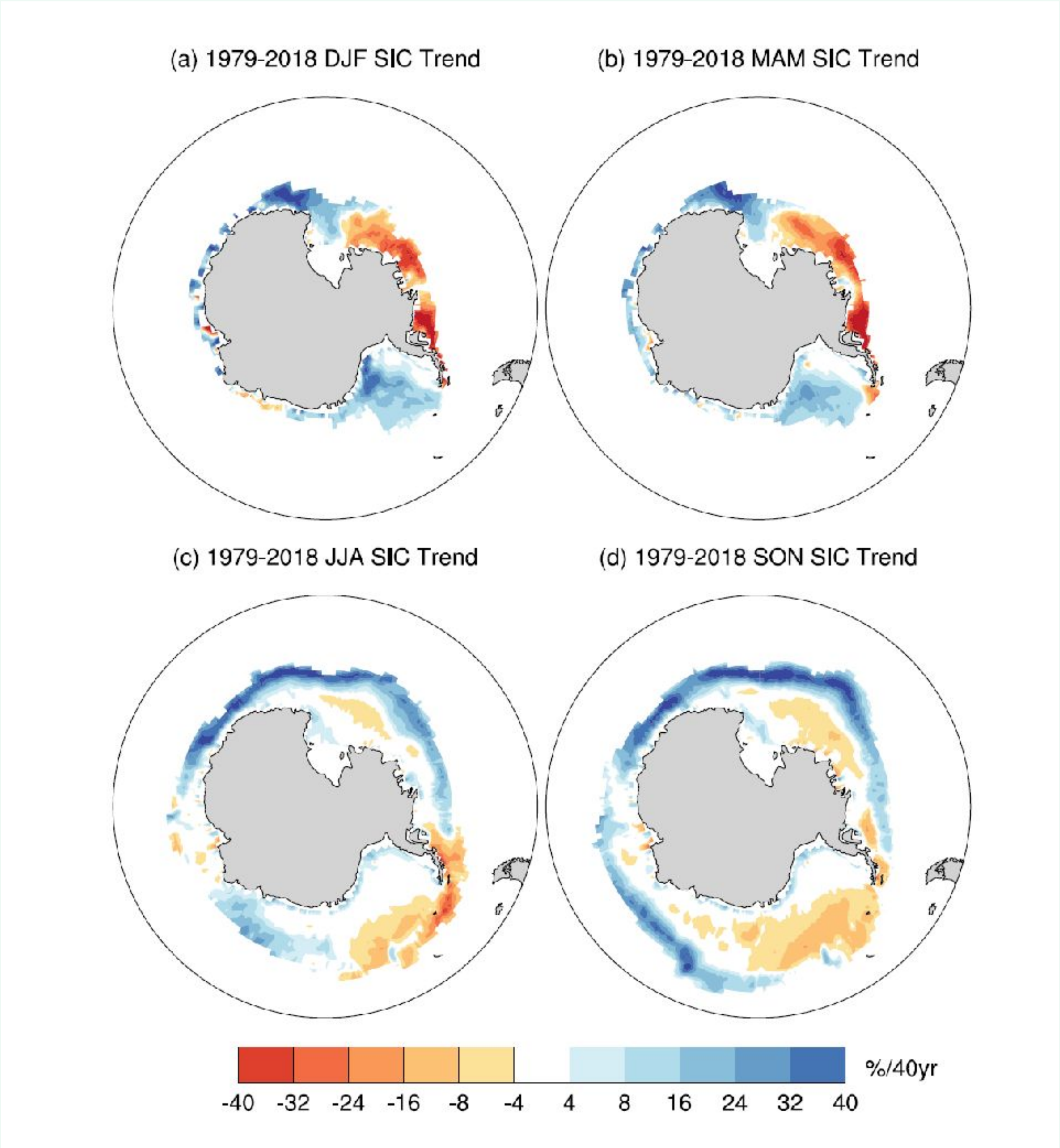
- Early and recent modeling studies suggest that idealized Antarctic sea ice expansion or projected Antarctic sea ice loss might have significant impacts on SH atmospheric circulation in austral cold seasons (Raphael 2003; Lachlan-Cope 2005; Raphael et al. 2011; Kidston et al. 2011; Bader et al. 2013; Menendez et al. 1999; England et al. 2017; Smith et al. 2017; Bracegirdle et al. 2018).



Antarctic Dipole (ADP):
(1) the largest interannual variability in the Antarctic sea ice field,

(2) related to ENSO, Antarctic Oscillation (AAO), PSA and other forcings.

(Peterson and White 1998; Yuan and Martinson 2000; Hall and Visbeck 2002; Liu et al. 2004; Holland et al. 2005; Holland and Raphael 2006; Yuan and Li 2008).



Seasonal trends of Antarctic SIC show some projections onto the ADP.

- Wu, Q., and X. Zhang (2011): Observed evidence of an impact of the Antarctic sea ice dipole on the Antarctic Oscillation. Journal of Climate. 24. 4508-4518.

- Wu, Q., S. Wang, S. Liu, X. Zhang, S. Schroeder, and Y. Yao (2020): Modeling atmospheric responses to Antarctic sea ice dipole-like anomalies (To be submitted to Journal of Climate).

Maximum Covariance analysis (MCA, SVD)

- Satellite sea ice concentration (SIC); NCEP Z500 in 1979-2008;
- The MCA is applied as a function of time lag and season to monthly SIC and Z500 anomalies in the domain from 20°S to 90°S.
- Sets of three successive months (e.g., JFM) were considered with SIC leading or lagging Z500 anomalies.
- Monte Carlo approach evaluates significance of statistics (the squared covariance SC, the temporal correlation *r*).

Observed air-ice interactions: (1) dominantly by the atmospheric forcing on Antarctic SIC throughout the year; (2) but a seasonality of Antarctic SIC impact on atmospheric circulation.

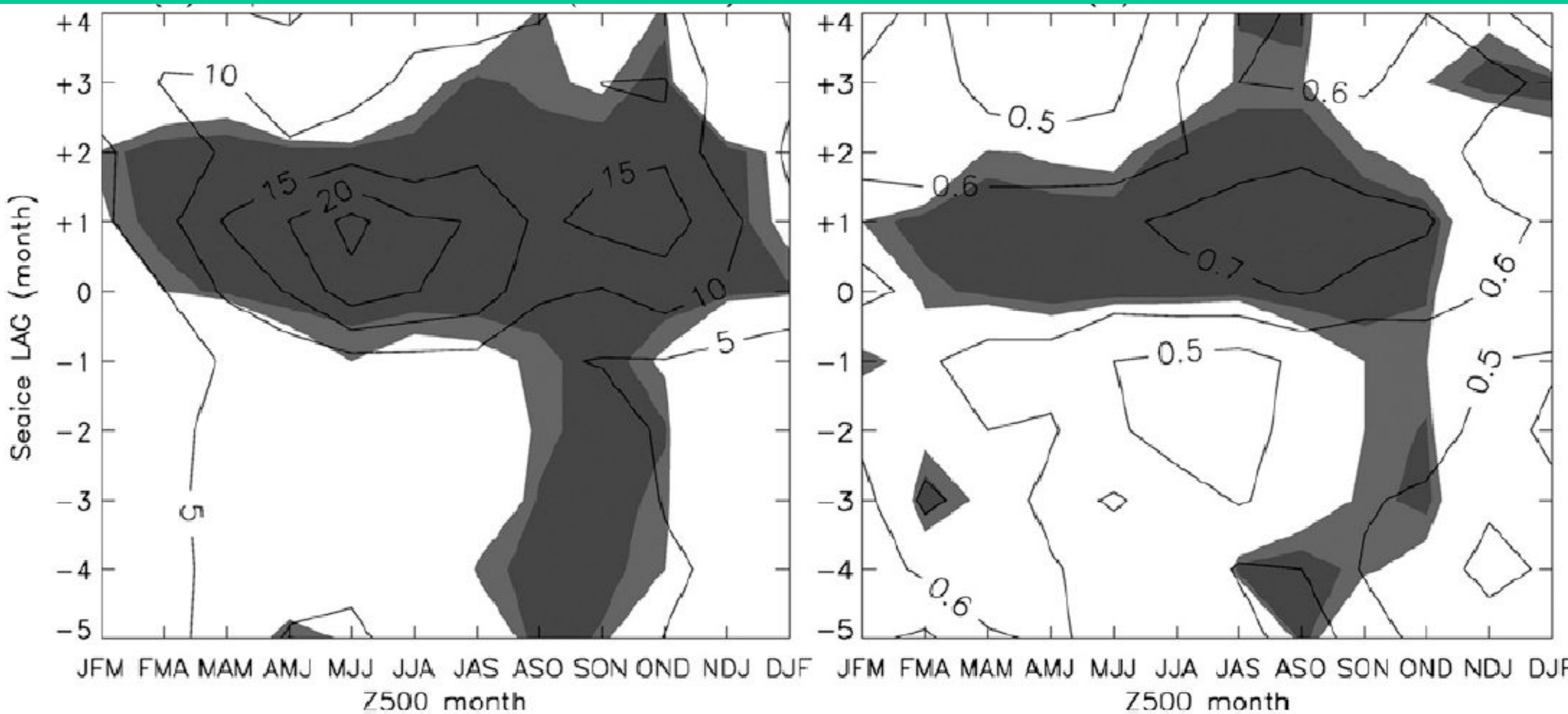
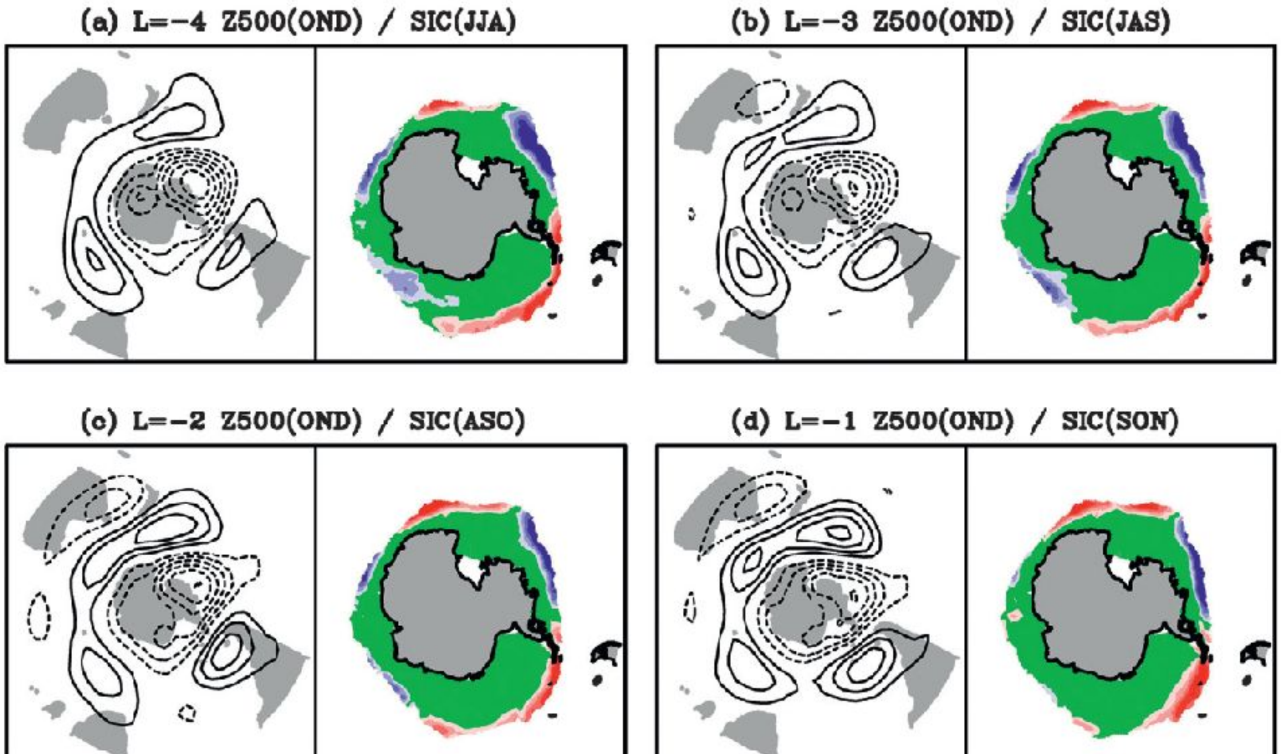


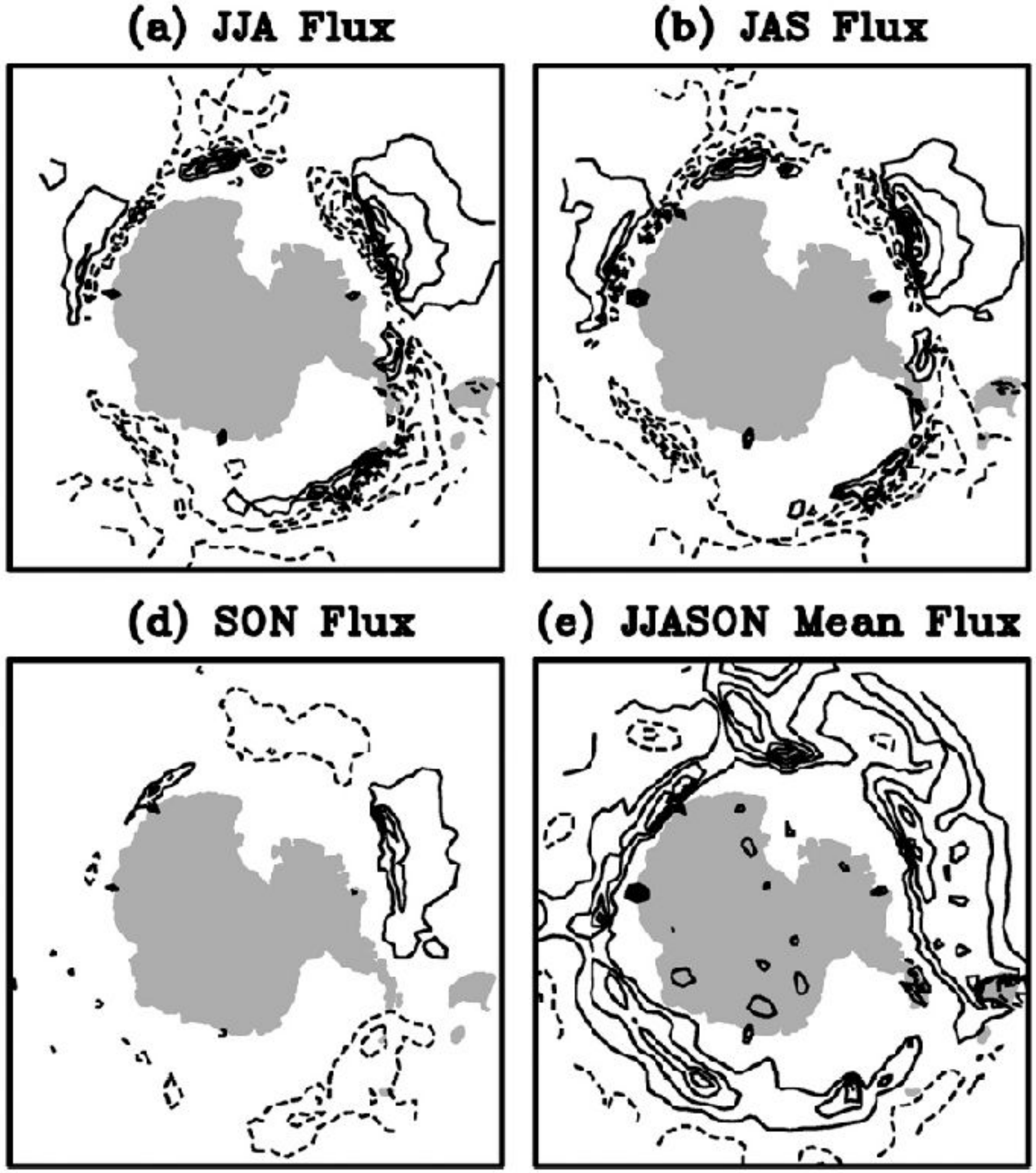
FIG. 1. The (a) SC and (b) correlation coefficient associated with the first MCA modes between anomaly fields of the Z500 (90°–20°S) and the hemispheric SIC as a function of seasons and lags. SIC leads Z500 at negative lags indicated (in months) on the *y* axis while the *x* axis denotes the months assigned to Z500. Shading indicates the 10% (heavy) and 5% (the most heavy) significance level.



Similar MCA patterns for ASO and SON Z500 at lags –4 to –1 months;

A persistent ADP-like SIC anomaly from austral winter to spring would cause a polarization of AAO toward its positive phase 1-4 months later;

Cross-validated AAO correlation skill is about 0.33-0.50, indicating that about 10-25% of the AAO variance in ASO, SON and OND can be predicted from the ADP SIC anomalies 2-3 months earlier.



Near the ice edge, surface energy heat fluxes associated with the ADP SIC anomalies are of similar magnitude to climatological heat fluxes.

FIG. 4. (a)–(d) Composite response in JJA to SON surface energy heat flux of negative minus positive months of the MCA–SIC time series associated with homogeneous SIC pattern in Figs. 2a–d from JJA to SON seasons exceeding 1.0 standard deviation in absolute values. (e) Climatology JJASON mean surface energy flux. Contour interval is 20 W m^{-2}. Negative contours are dashed and the zero line is omitted.

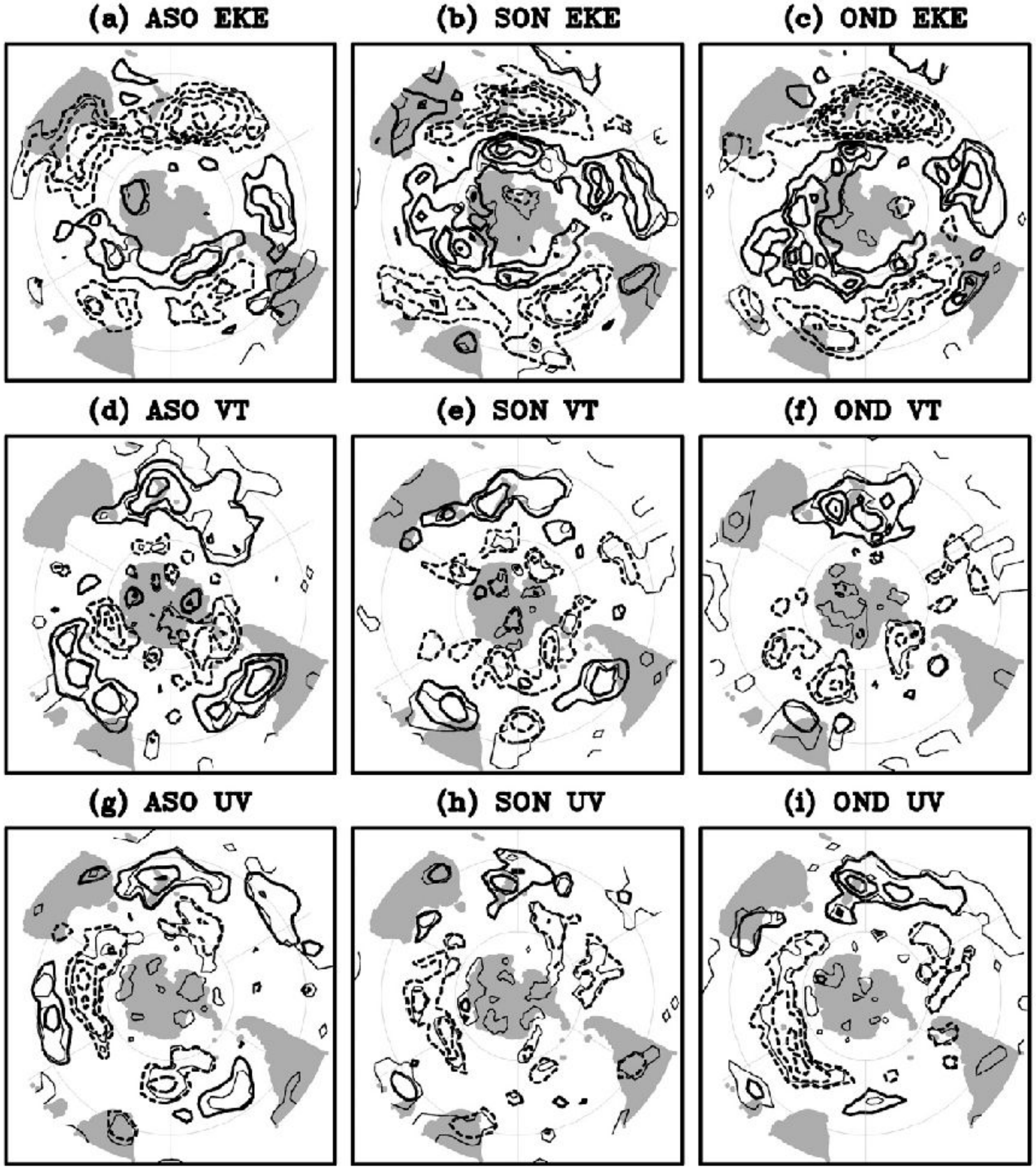
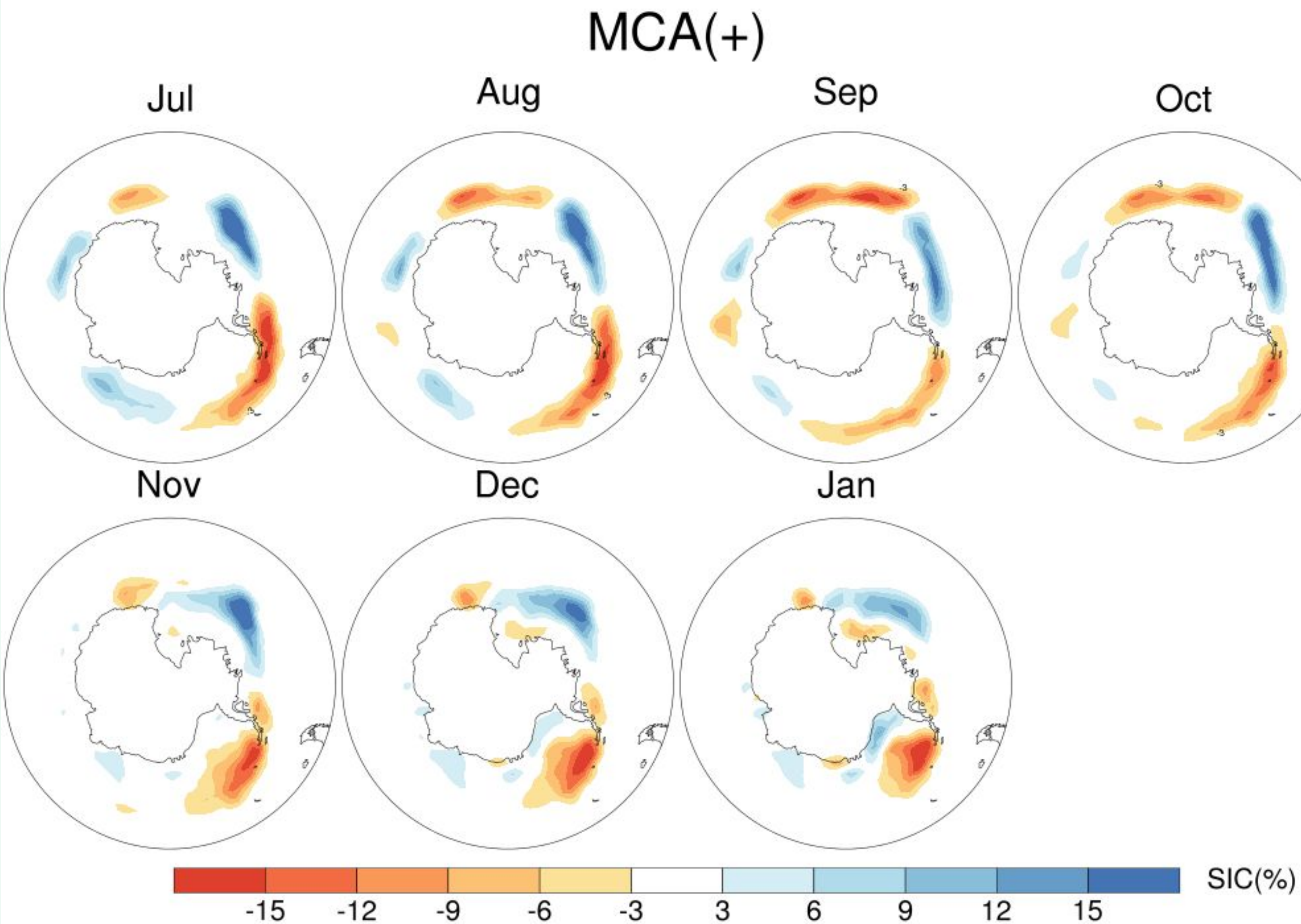


FIG. 5. Simultaneous and lagged regression maps of (a)–(c) bandpass-filtered 300-hPa transient eddy kinetic energy $[(u'^2 + v'^2)/2]$, (d)–(f) 700-hPa transient eddy meridional heat flux $(v'T')$, and (g)–(i) 300-hPa transient eddy momentum flux $(u'v')$ to the MCA–SIC time series at lag −2 when Z500 is fixed at OND. Contour interval is 2.5 $m^2\ s^{-2}$ for $\overline{(u'^2 + v'^2)/2}$, 0.25 K m s^{-1} for $\overline{v'T'}$, and 2 $m^2\ s^{-2}$ for $\overline{u'v'}$. Negative contours are dashed and the zero line is omitted. The thin lines indicate the estimated 5% significance level.

Poleward shift of storm track associated with the ADP ice anomalies

Anomalous poleward (equatorward) eddy heat and momentum fluxes in the high-latitude (mid-latitude).

ADP SIC forcing from the MCA



CAM4 simulations

- CTR: with climatological monthly SIC and SST.
- PERT: the ADP-like SIC anomaly in the MCA is added to climatological monthly SIC from July to following January.
- Each integration of 100 ensembles.
- The modelled atmospheric response is defined as the ensemble-mean difference between PERT and CTR.

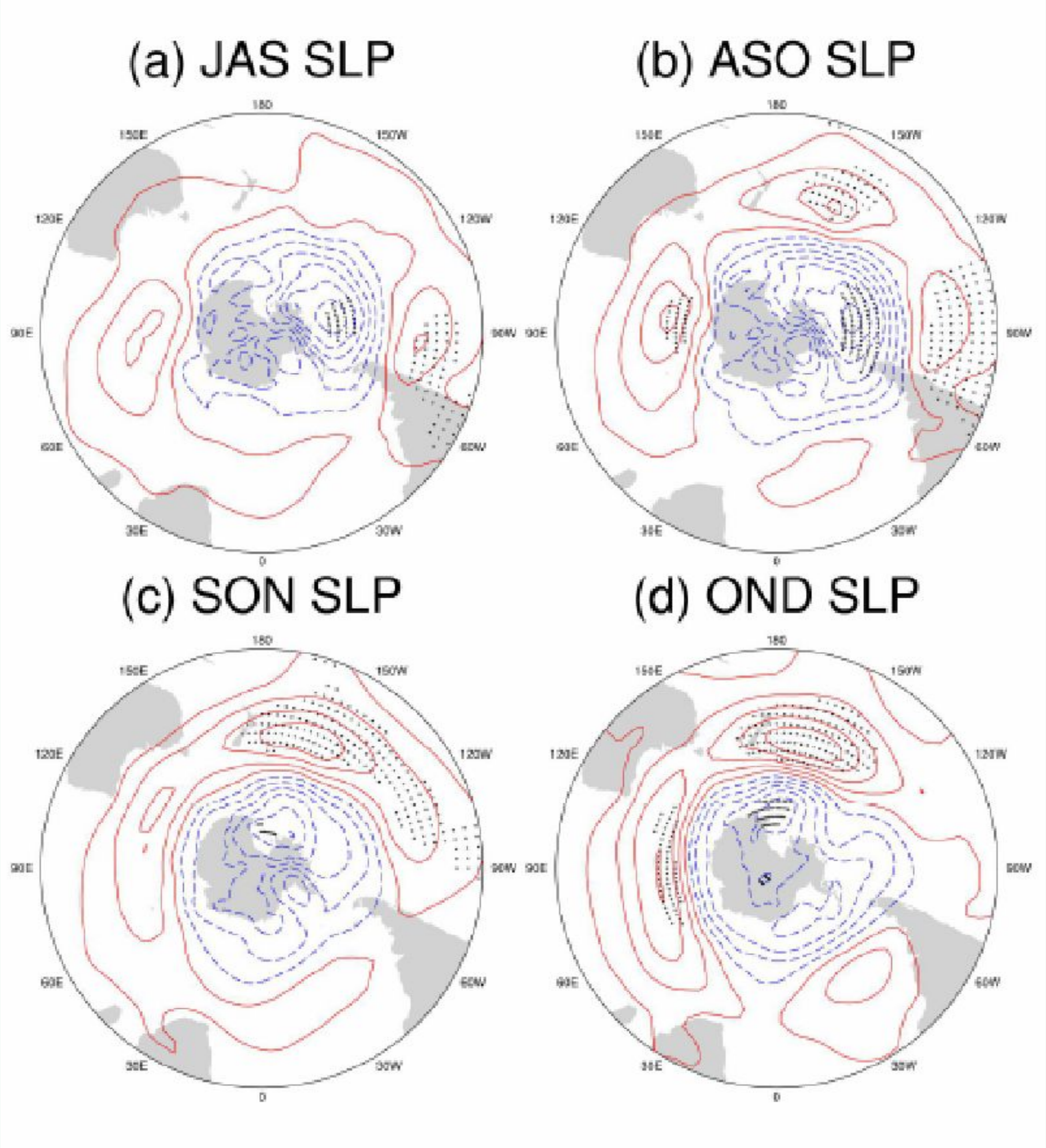


Figure 4. Seasonal mean SLP responses (0.25 mb). Black dots indicate > 95% statistical confidence interval.

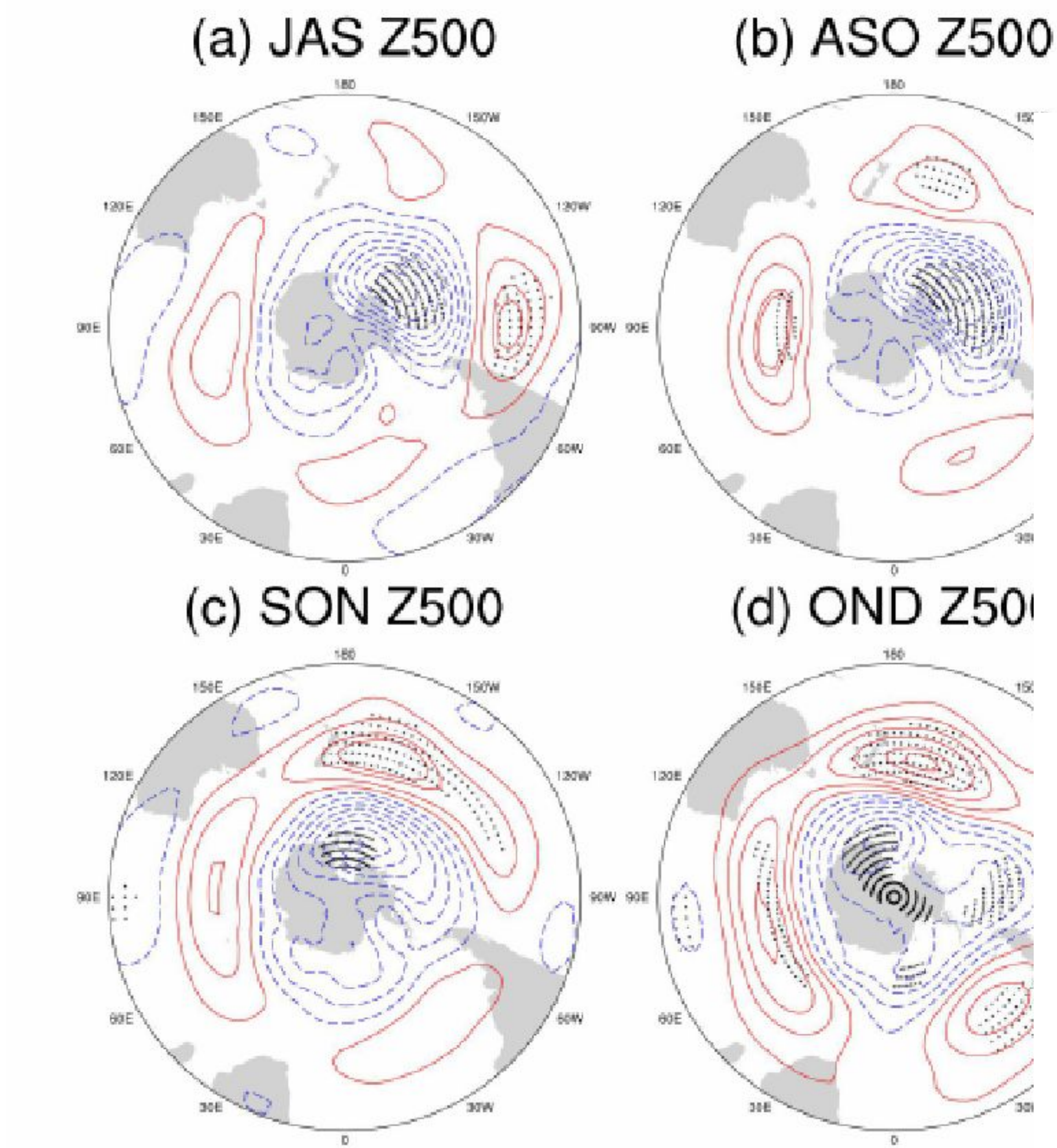
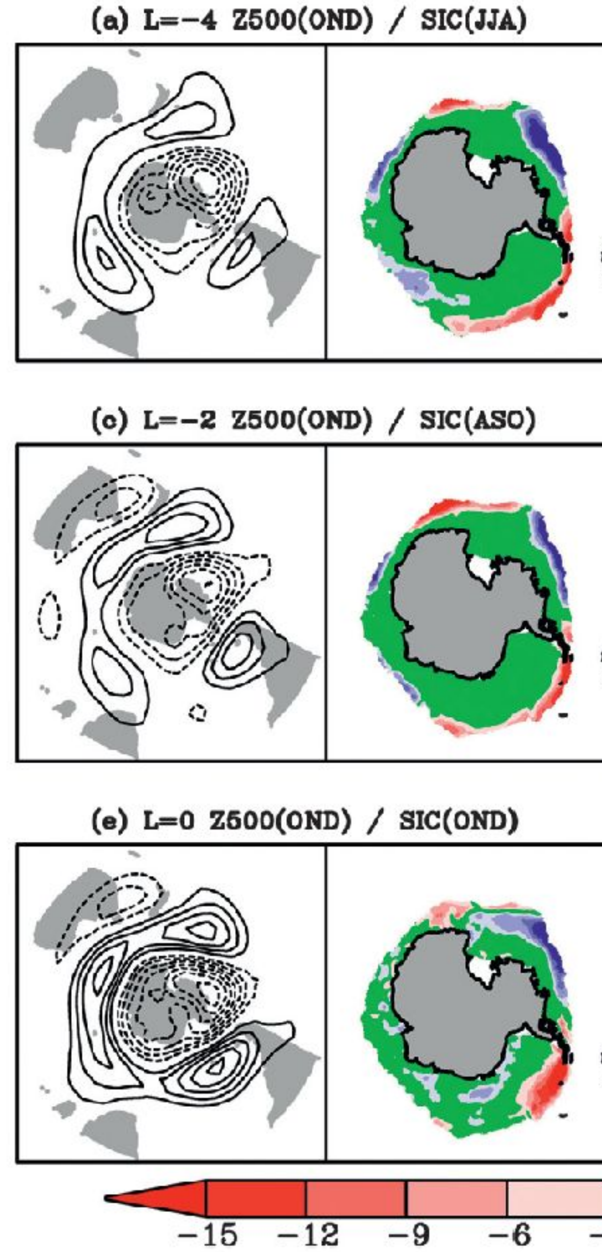


Figure 5. Seasonal mean Z500 responses (2.5



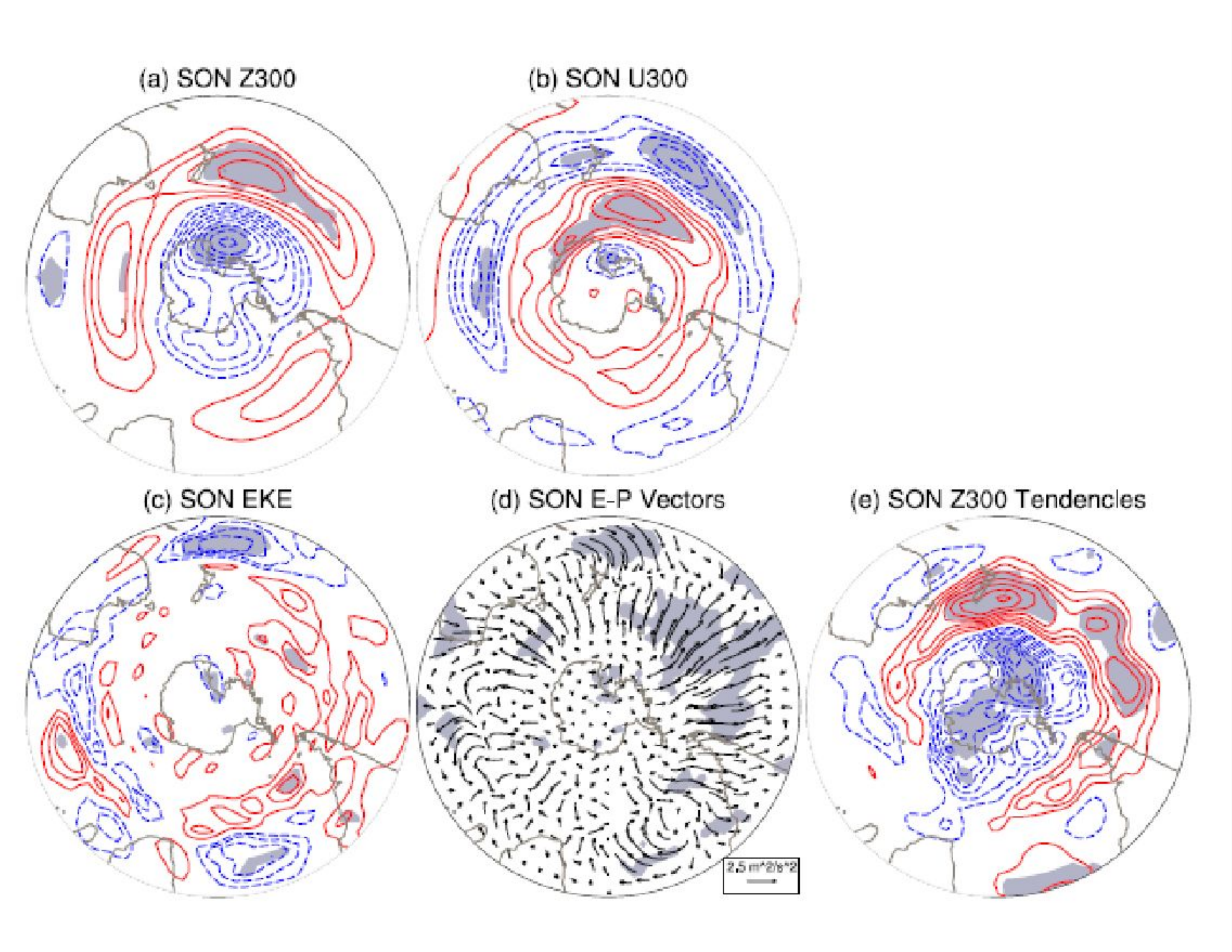


Figure 10. Ensemble-mean SON seasonal responses in (a) Z300; (b) U300; (c) eddy kinetic energy, (d) Eliassen-Palm vectors, and (e) 300 hPa height tendencies.

Quantitative impacts of the eddy forcings on Z300

Where π is defined as convergence of the vorticity flux of transient eddies, the geopotential height tendency ∂z / ∂t is proportional to the inverse Laplacian of π:

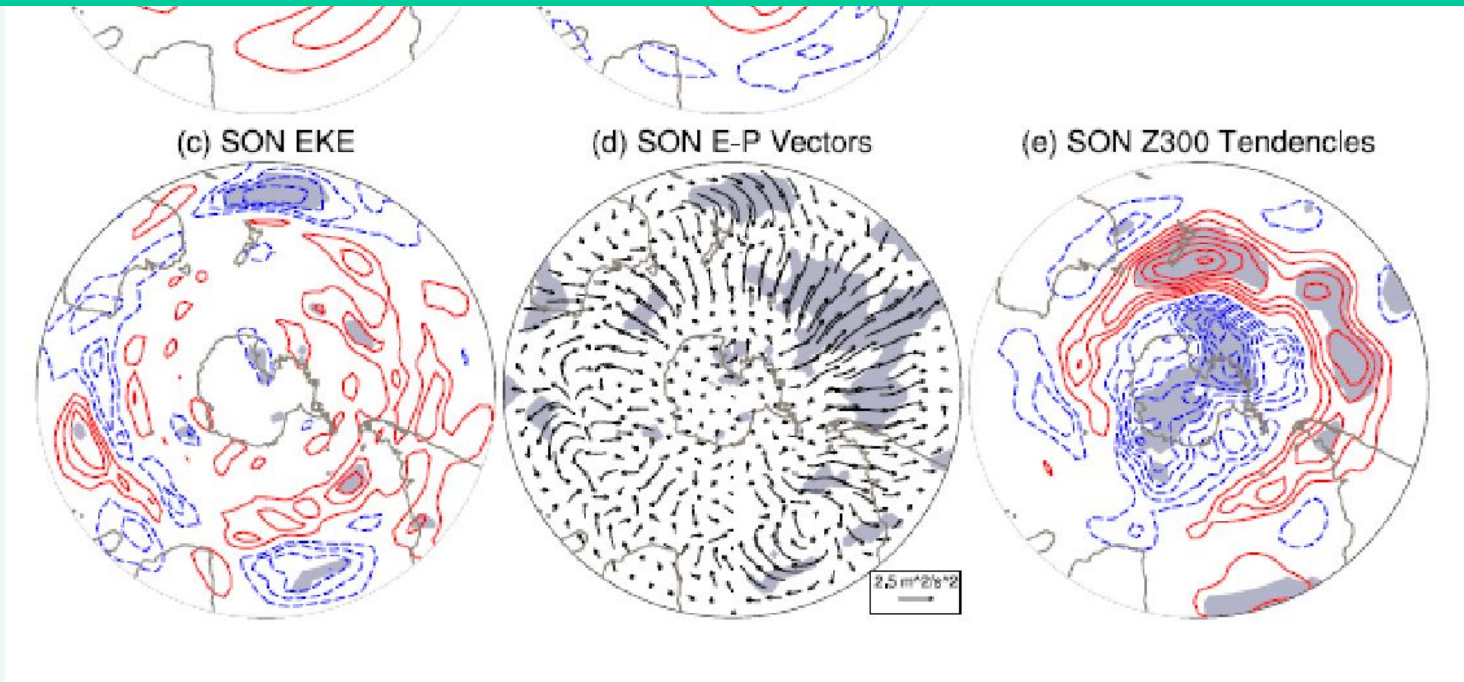
$$\frac{\partial z}{\partial t} = \frac{f}{g}\nabla^{-2}\pi \qquad (1)$$

$$\pi \equiv \frac{1}{a^2\cos\theta}\left(\frac{\partial}{\partial\theta}\frac{1}{\cos\theta}\frac{\partial}{\partial\theta}cos^2\theta - \frac{1}{\cos\theta}\frac{\partial^2}{\partial\lambda^2}\right)\overline{u'v'} + \frac{1}{a^2cos^2\theta}\frac{\partial^2}{\partial\lambda\partial\theta}\cos\theta\left(\overline{u'^2} - \overline{v'^2}\right) \qquad (2)$$

where a = earth radius, f = Coriolis parameter, g = gravitational acceleration, λ = latitude, and θ = longitude.

Lau, N. (1988): Variability in the observed midlatitude storm tracks in relation to low-frequency changes in the circulation pattern. *J. Atmos. Sci.*, **45**, 2718–2743.

The growth and maintenance of the large-scale AAO-like circulation response in auastral winter to springtime to the persistent ADP SIC anomalies involves feedback by synoptic transient eddies.



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Summary

- We provide observational and modelling evidences of significant impacts of Antarctic SIC dipole anomalies on SH Circulations from austral winter to springtime.
- Such forcing of the AAO by the ADP-like SIC anomalies in early seasons provides an implication for skillful predictability of SH atmospheric variability.

Other ongoing sea ice studies

- Examining impacts of observed Antarctic sea ice expansion
- Simulating impacts of sudden Antarctic sea ice retreat in late 2016
- Examining the role of Antarctic Ozone recovery on Antarctic sea ice expansions
- Studying interactions between Tibetan Plateau snow and Arctic sea ice