Baroclinic anomalies associated with the SAM: Roles of synoptic and low-frequency eddies

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Introduction

Southern Hemisphere Annular mode (SAM) is often described as a persistent latitudinal shift of the mid-latitude jet. Observational studies suggested that the persistence of the SAM is a consequence of a positive feedback between the synoptic eddy momentum forcing and the zonal flow, and the persistent shift of the jet is often followed by a shift of the maximum low-level barolinic zone where the eddy generation is strongest. This latitudinal shift of baroclinicity may prolong the time scale of the SAM through a positive feedback loop. What processes sustain the persistent shift of baroclinic zone?

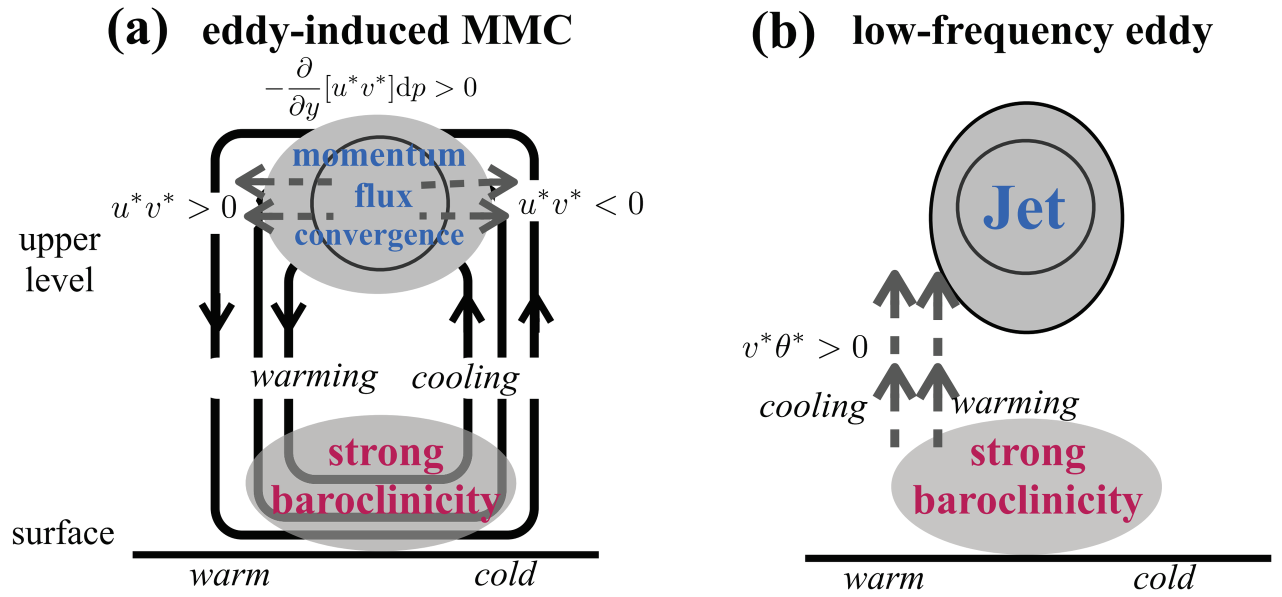

Figure 1: *Schematics illustrating the mechanisms through which (a) the eddy-induced MMC suggested by Robinson [2006] and (b) the low-frequency eddies suggested by Zhang et al. [2012] act to enhance the low-level baroclinicity.*

In this study, by explicitly diagnosing the eddy-induced MMC, different dynamical processes suggested in Figure 1 will be examined using the reanalysis data, and how the synoptic and low-frequency eddies work together in sustaining the baroclinic anomalies in the SAM will be investigated.

Dataset and Methodology

- 44-yr (1958-2001) ERA-40 daily (1200UTC) wind and temperature data at constant pressure levels for the Southern Hemisphere are used.
- Divide the eddy component into high- and low-frequency parts.
- The eddy effect on the low-level baroclinicity shift is examined by assessing the direct eddy thermal forcing and indirect forcing through eddy-induced MMC.

Tendency equation for baroclinicity under QG approximation:

$$\frac{\partial}{\partial t}\left(-\frac{\partial}{\partial y}[T]\right) = \frac{\partial^2}{\partial y^2}[v^*T^*] - \frac{\partial}{\partial y}\Gamma[\omega] - R \qquad (1)$$

- The eddy-induced MMC by high- and low-frequency eddies are explicitily diagnosed by solving the zonally-symmetric Quasi-geostrophic Omega equation.

$$L\omega(p,\mu) = \frac{2\Omega ap}{R\Gamma}\frac{\partial}{\partial\mu}\left[\frac{(1-\mu^2)^{1/2}}{\mu}\frac{\partial F}{\partial p}\right] - \Gamma^{-1}\frac{\partial}{\partial\mu}\left[\frac{(1-\mu^2)}{\mu^2}\frac{\partial Q}{\partial\mu}\right], \qquad (2)$$

$F : [u^*v^*] driven; Q : [v^*T^*] driven$

Baroclinic Anomalies Associated With SAM

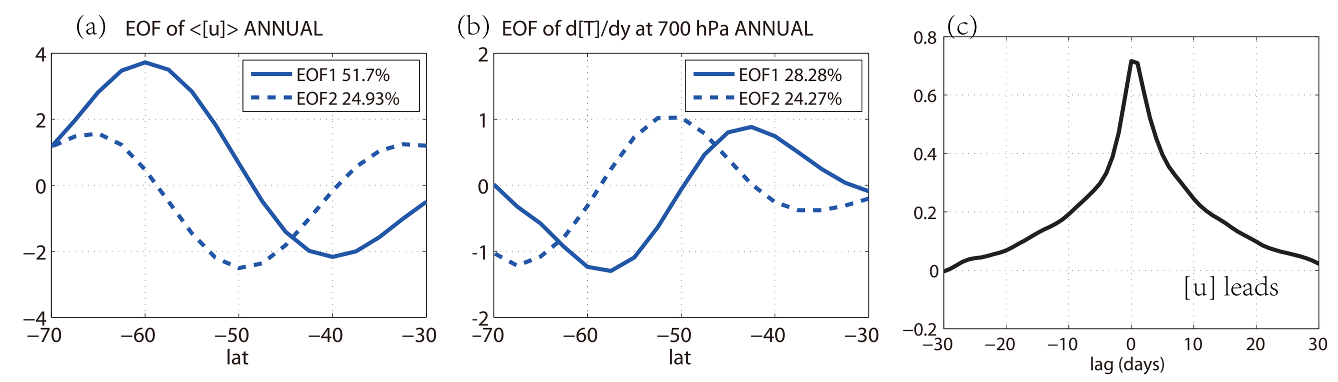

Figure 2: *(a) Leading EOFs of zonal wind $<[u]>$. (b) First two EOFs of zonal-mean meridional temperature gradient at 700 hPa. (c) Lagged correlation between PC1 of 700 hPa meridional temperature gradient and UPC1.*

- The jet shift is followed by a latitudinal shift of the low-level baroclinicity

Roles of High- and Low-Frequency Eddies

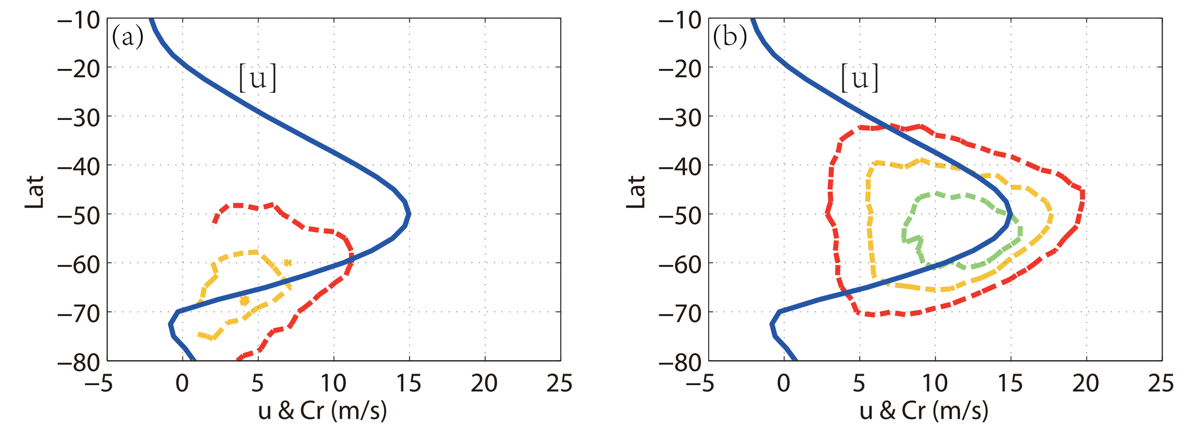

Figure 3: *Cospectra of 700 hPa [[v*T*] as a function of zonal phase speed and latitude for zonal wavenumbers (a) 1-4 and (b) 5-8.*

- Synoptic eddy peaks at the jet center, while low-frequency eddy heat flux centered at the jet flank. The different roles played by high and low-frequency eddies might be attributed to their distinct meridional distribution relative to the mid-latitude jet.

Direct Forcing vs. Indirect Forcing

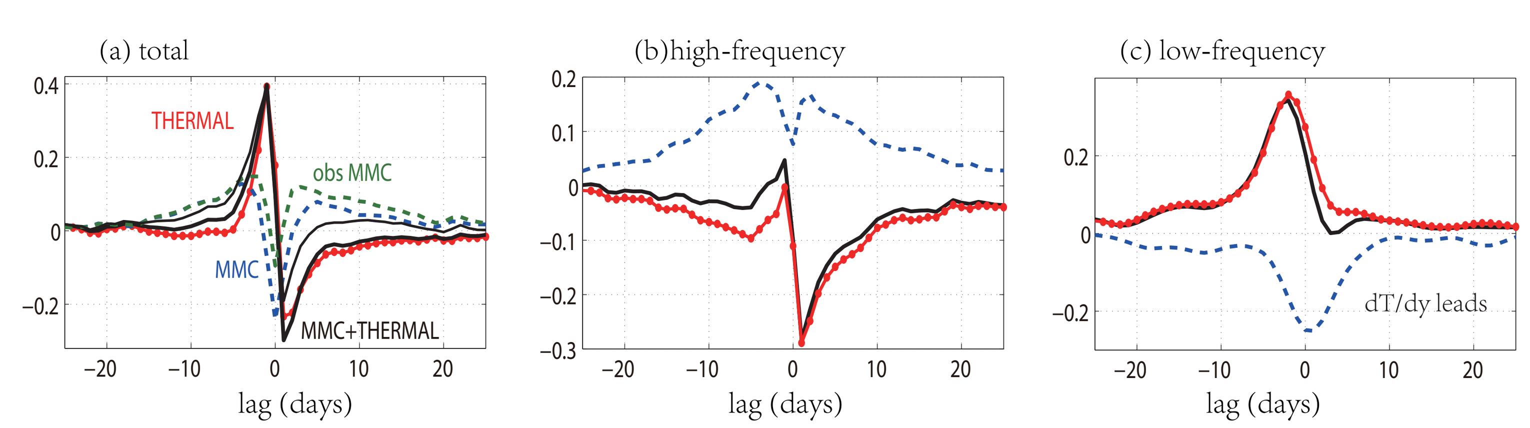

Figure 4: *Lagged correlations between PC1 of baroclinicity at 700 hPa and time series from the direct eddy thermal forcing, indirect eddy-induced MMC forcing and the sum of the two by (a) total (b) high- and (c) low-frequency eddies*

- The direct eddy thermal forcing shows a strong driving effect on the latitudinal shift of baroclnicity. The eddy-induced MMC acts to enhance and extend the baroclinic anomalies.
- At short lags, low-frequency eddy thermal forcing strongly leads and drives the shift of the baroclincity. While at long lags, synoptic eddy induced MMC plays a dominant role in extending the baroclinic anomalies.

Eddy-Induced MMC: Momentum Flux vs. Heat Flux

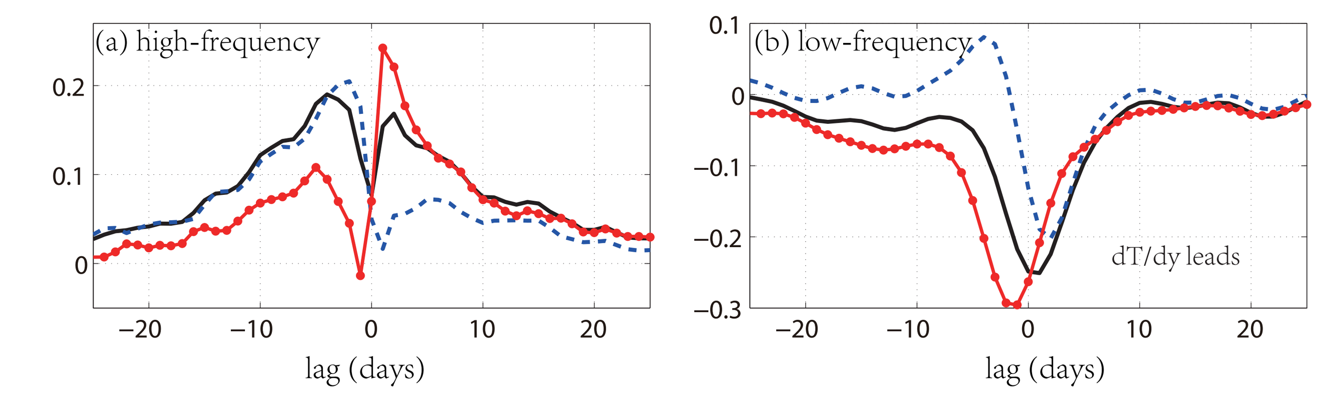

Figure 5: *Lagged correlations between PC1 of baroclinicity at 700 hPa and forcing time series from the MMC driven by (a) high- and (b) low-frequency eddy momentum flux, heat flux and eddy momentum + heat flux together.*

- For the high-frequency eddy, momentum flux and heat flux play different roles, with the former leading the baroclinic anomalies and the latter acting to extend the baroclinic anomalies.
- For the low-frequency eddy induced MMC, both the momentum and heat flux driven parts show damping effect on the baroclinic anomalies.

Diabatic Heating and Surface Friction

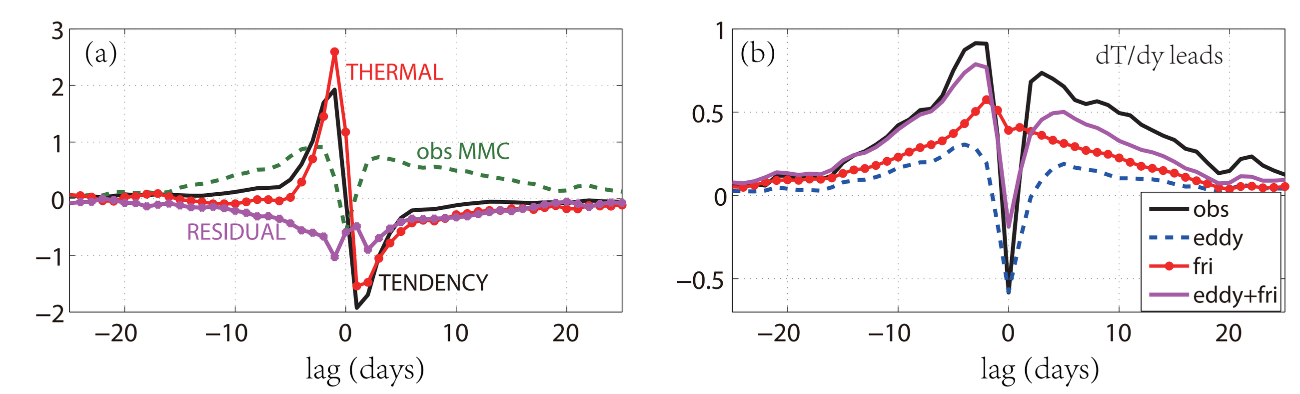

Figure 6: *Lagged covariance between zonal mean baroclinicity and (a) its main forcings, and the (b) forcings of the Observed MMC, the MMC driven by eddy, friction, and the two together.*

- Diabatic heating plays a secondary role and always acts to damp the baroclinic anomalies. Surface friction, through the friction-induced MMC, is also important for extending the baroclinic anomalies.

Conclusions

- The jet shift is followed by a latitudinal displacement of the low-level baroclinicity.
- In addition to the indirect synoptic eddy induced MMC, the direct low-frequency eddy thermal forcing is also significant for driving the baroclinic anomalies. These two processes together prevail over the direct baroclinicity deduction by synoptic eddies.
- The different roles of the MMC induced by synoptic eddy momentum flux and heat flux are emphasized, with the former leading the baroclinic anomalies and the latter acting to extend the baroclinic anomalies

References

Zhang, Y., X. Yang, Y. Nie, and G. Chen, 2012: Annular mode like variation in a multi-layer QG model. J. Atmos. Sci., 69, 2940-2958.

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