Effect of Antarctic orography on southern hemisphere jet streams

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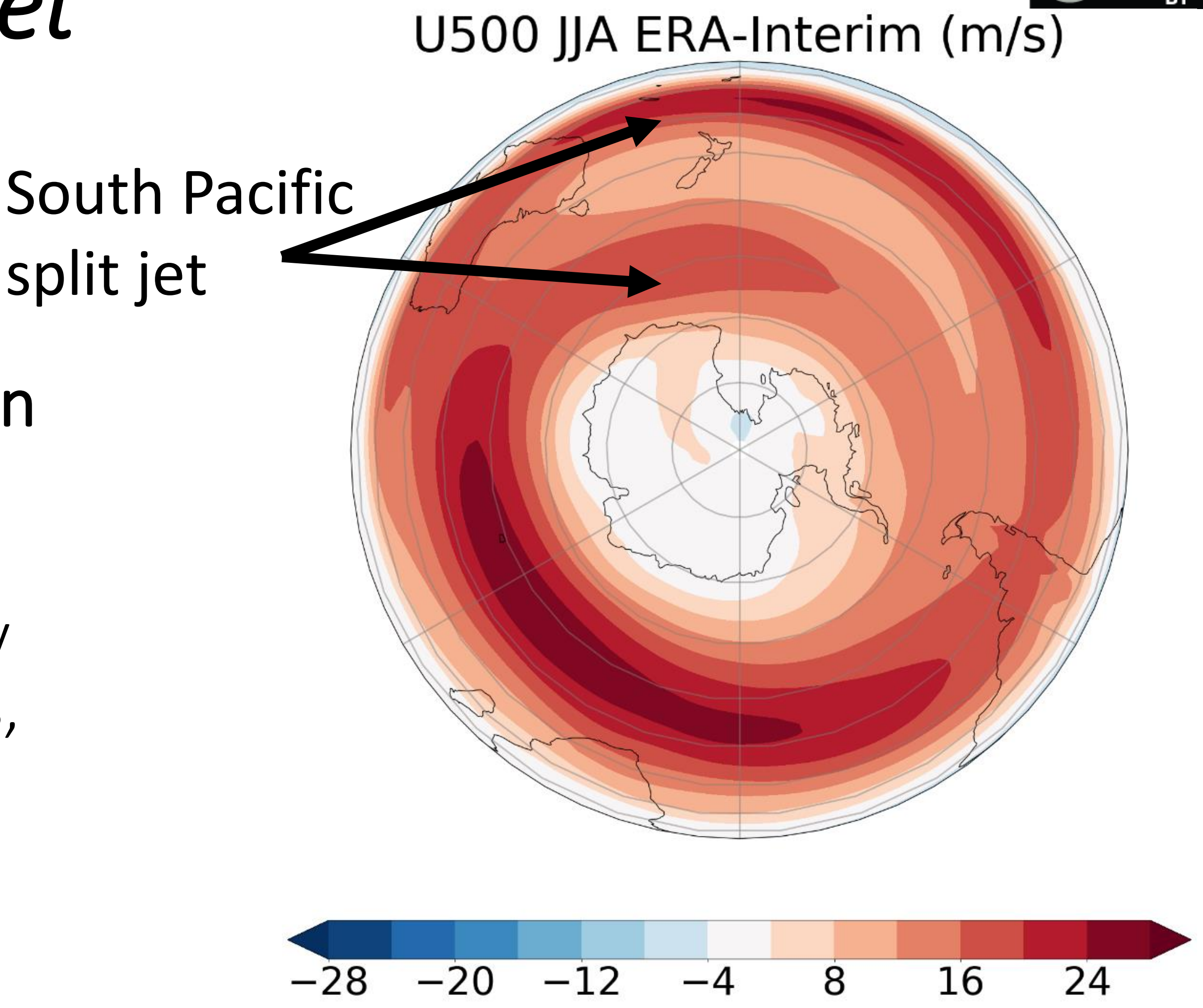
Characteristic split jet pattern found in SH winter.

What factors shape the mean state?

1) Tropical SSTs via stationary waves (Inatsu and Hoskins, 2004)

2) Antarctic orography?



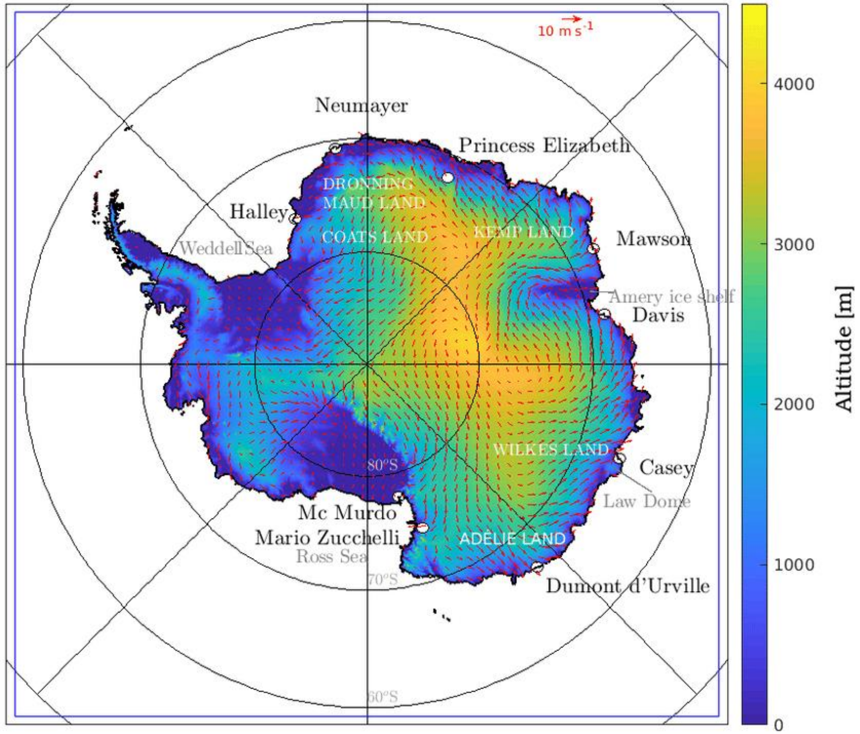
The idea: Antarctic orography alters jet structure through modification of transient eddy propagation and shape

- A potential vorticity gradient is required for Rossby wave propagation.

- In the atmosphere PV gradients are generally weak at high latitudes as β is small. Hence a jet at high latitudes is only enhanced on its equatorward side by meridional wave propagation.

- In the ocean, variations in fluid depth give rise to potential vorticity gradients.

- Antarctic surface is 3-4km above sea level giving substantial perturbation to fluid depth, thus altering the column potential vorticity.

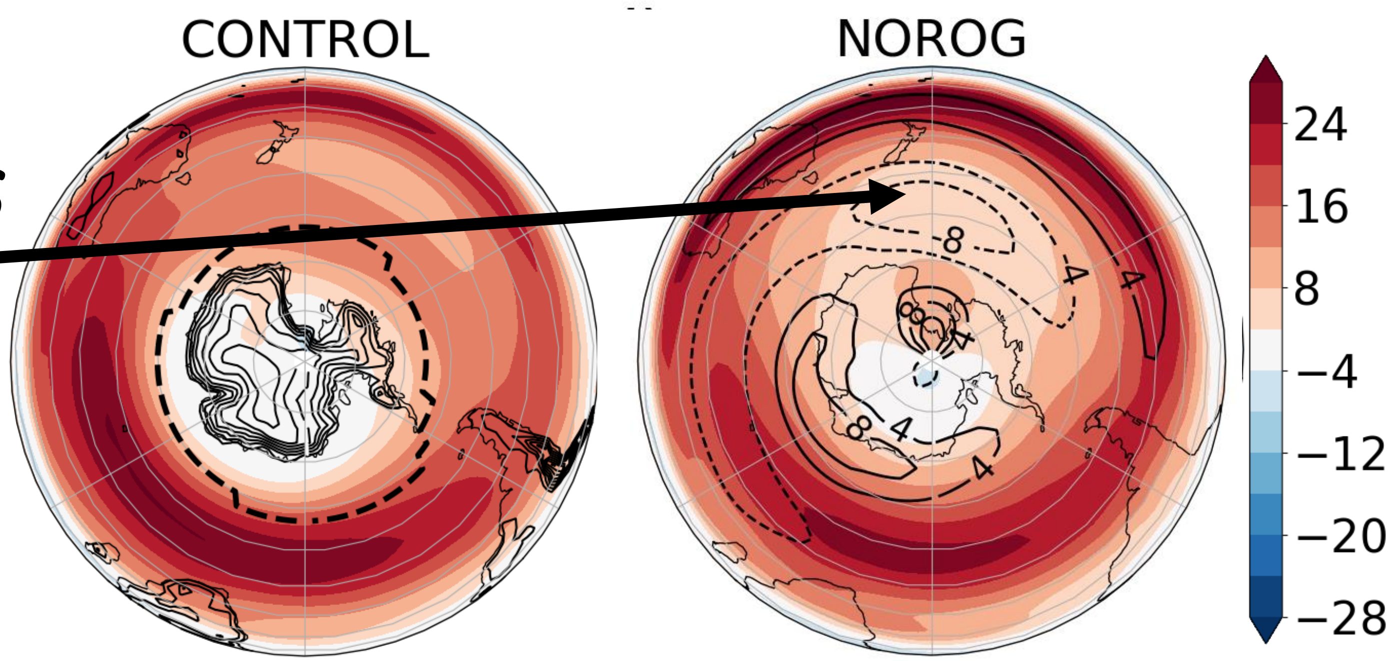


Map of Antarctic orography (Vignon et al, 2019)

Idealised AGCM setup

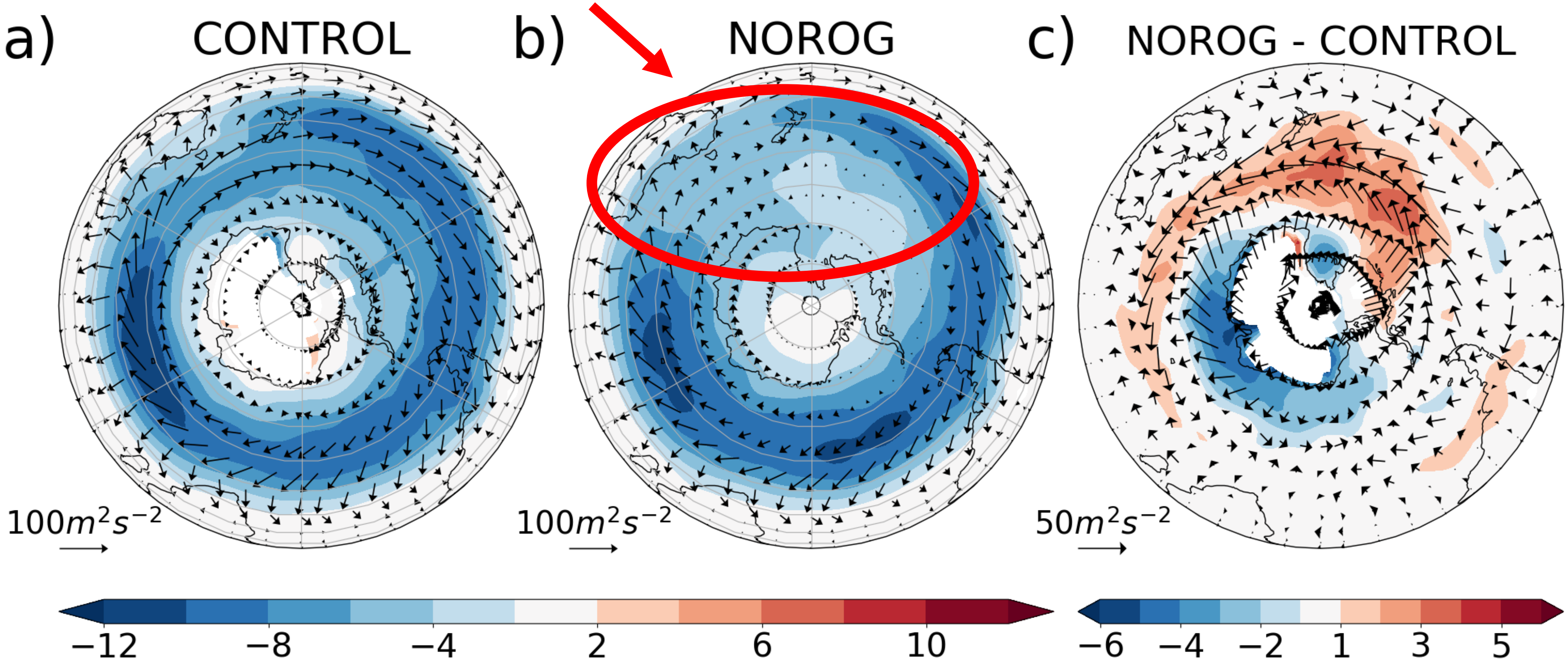
- Atmosphere-only simulations using *Isca* modelling framework (Vallis et al, 2018)
- Forced by seasonally varying SSTs and sea ice with realistic land and orography.
- **Experiments with (CONTROL) and without Antarctic orography (NOROG)**
- RRTM radiation, simple convection, boundary layer processes, evap. and precip.
- 30 year runs at T42 resolution (2.8° at equator) with 40 pressure levels.

Removing orography destroys the polar front jet



500hPa zonal wind in colours with difference from CONTROL shown by contours

Transient eddy fluxes substantially weakened without orography



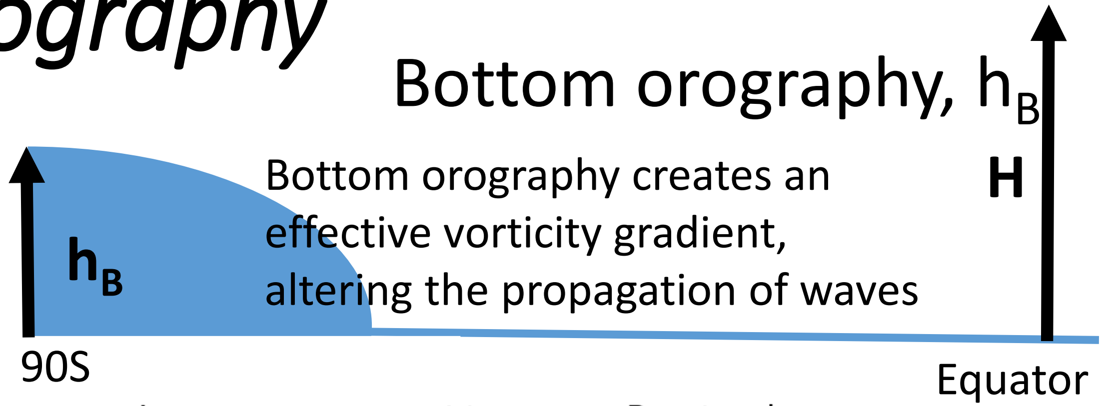
E vectors (Hoskins et al, 1983) as vectors and eddy heat flux in colours

Can understand this using a barotropic model with and without bottom orography

$$\frac{D\zeta}{Dt} + \left(\beta + \frac{\zeta + f}{H}\frac{\partial h_B}{a\partial\phi}\right) v = S - r\zeta + \kappa\nabla^4\zeta$$

Variation in potential vorticity due to bottom orography (assume rigid lid at tropopause)

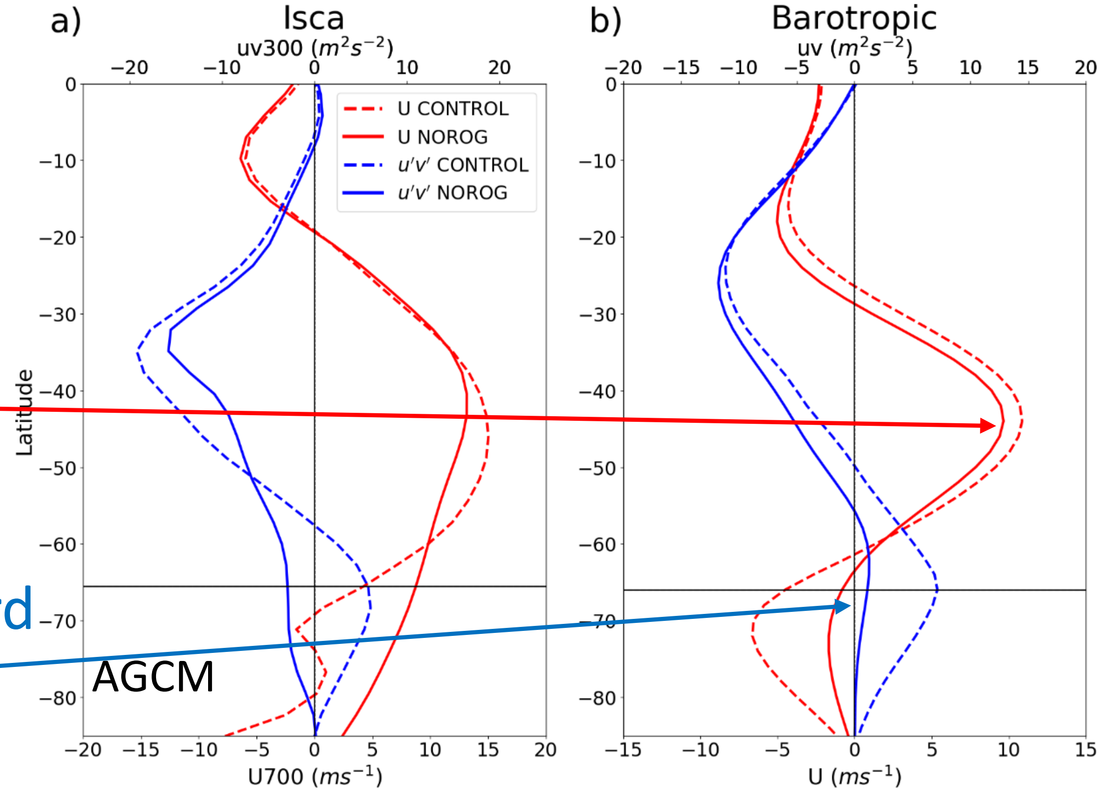
Random stirring mimics storm track



Bottom orography creates an effective vorticity gradient, altering the propagation of waves

Jet is weakened without orographic vorticity gradient

Concomitantly, high latitude equatorward momentum flux diminished.



Summary

- In the absence of Antarctic orography, AGCM simulations show the mid-latitude jet stream is severely weakened and the South Pacific split jet pattern destroyed.
- We have explained this using a simple barotropic model with bottom orography giving a PV gradient at high latitudes
- Orography alters the propagation and shape of eddies, introducing an equatorward momentum flux, enhancing the jet in mid-latitudes.

Patterson, M., Woollings, T., Bracegirdle, T. and Lewis, N. T. "Wintertime Southern Hemisphere jet streams shaped by interaction of transient eddies with Antarctic orography." Submitted to J. Clim.

References

Hoskins, B., James, I. and White, G. (1983) *"The Shape, Propagation and Mean-Flow Interaction of Large-Scale Weather Systems."* JAS.

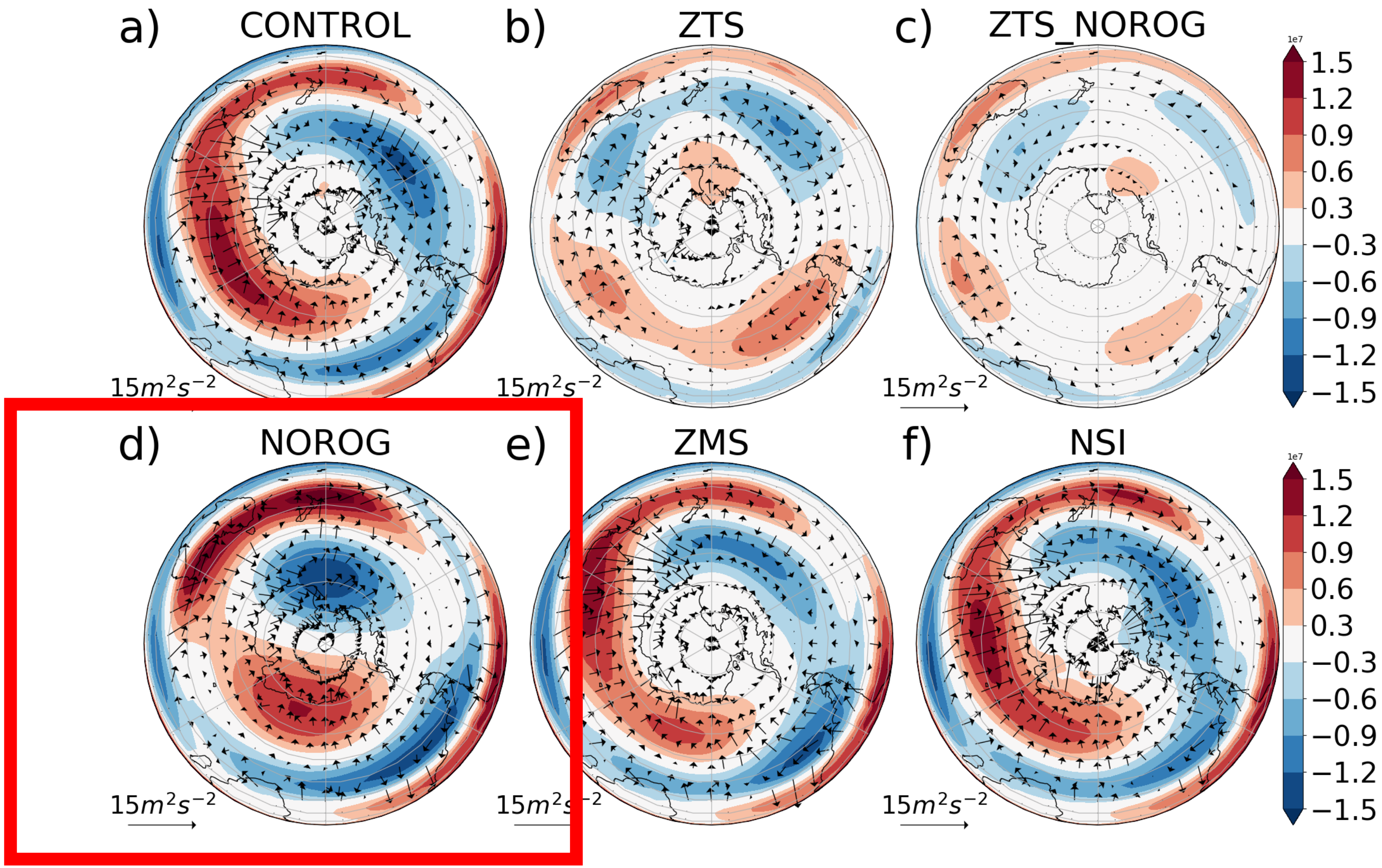
Inatsu, M. and Hoskins, B. (2004) *"The zonal asymmetry of the Southern Hemisphere winter storm track."* J. Clim.

Vallis, G., Colyer G., Geen, R., Gerber, E. Jucker, M., Maher, P., Paterson, A., Pietschnig, M., Penn, J., Thomson, S.(2018) *"Isca, v1.0: a framework for the global modelling of the atmospheres of Earth and other planets at varying levels of complexity."* GMD.

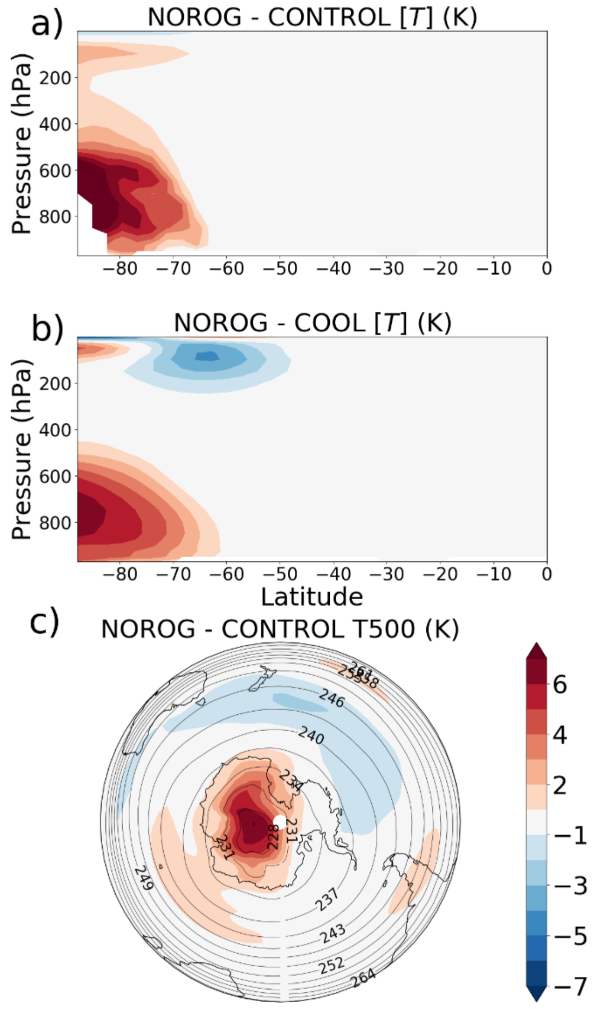
Vignon, E., Traullé, O. and Berne, A. (2019) *"On the fine vertical structure of the low troposphere over the coastal margins of East Antarctica."* ACP.

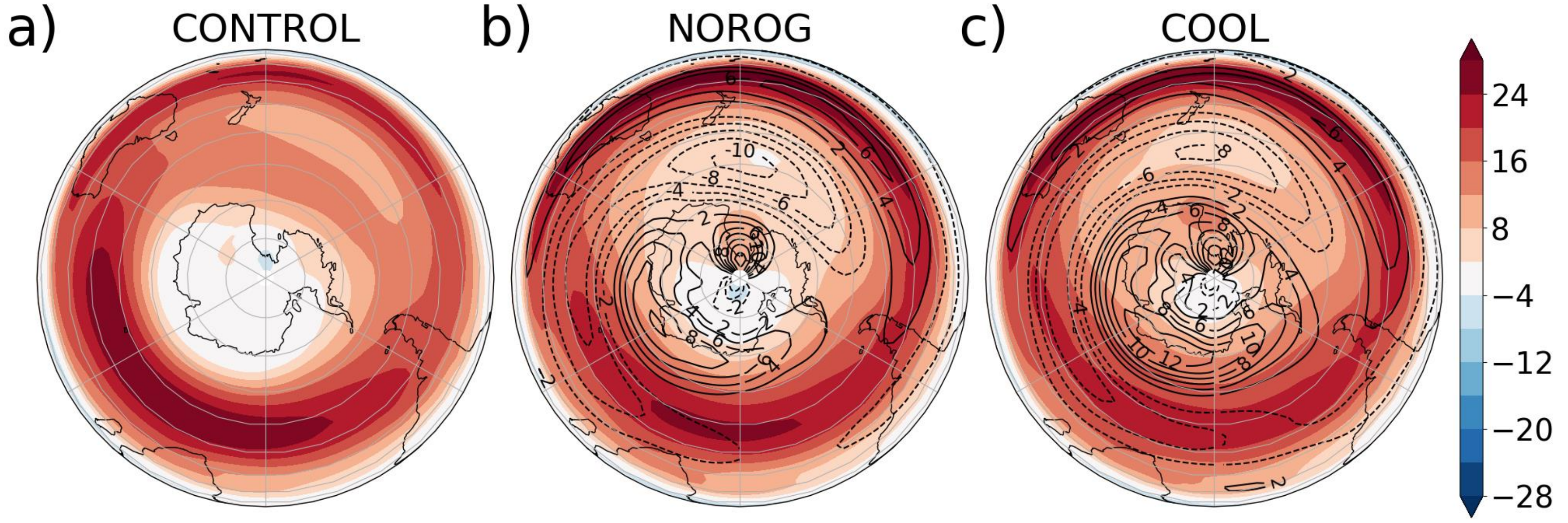
Extra slides

Stationary waves



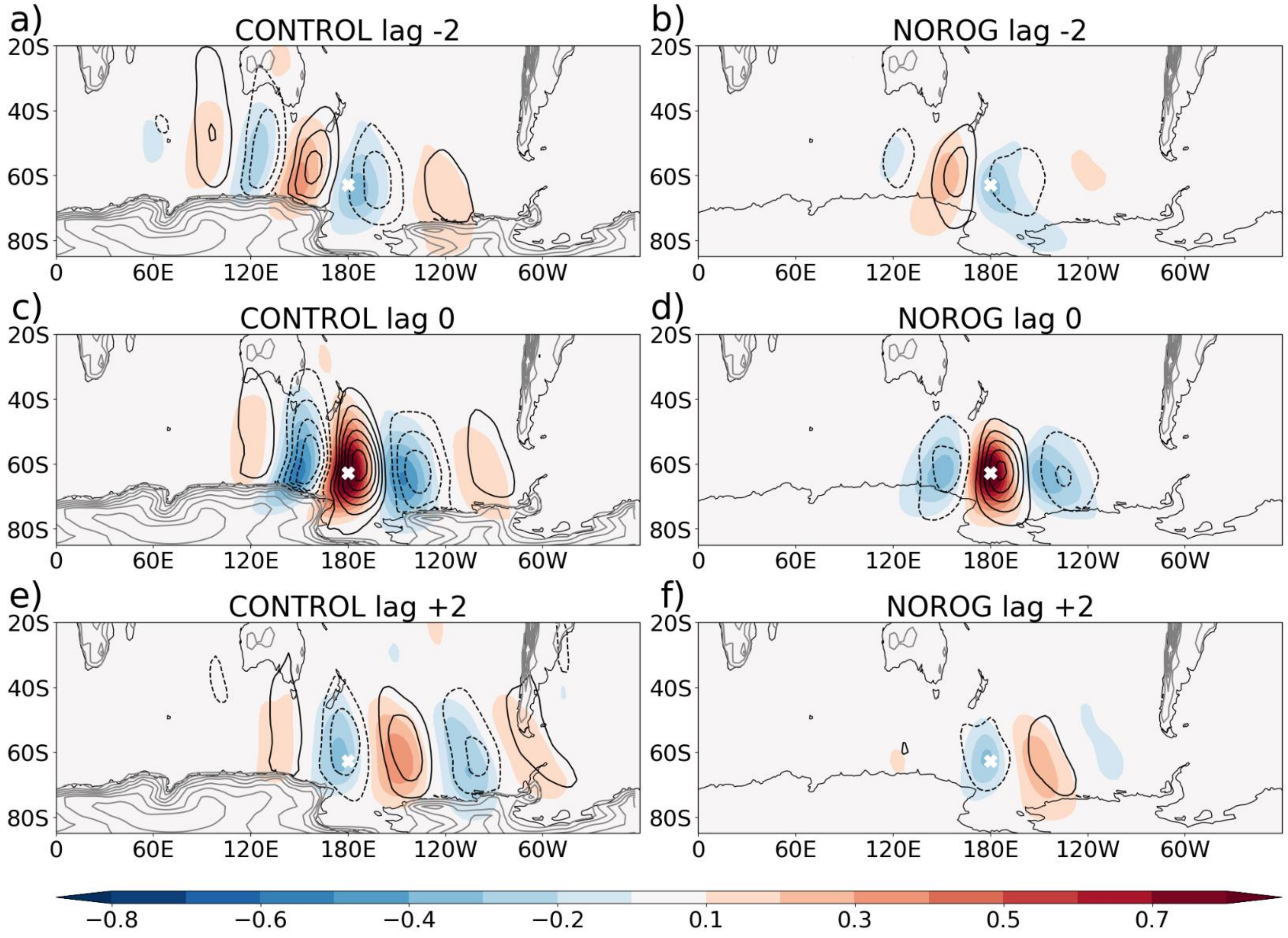
Removing orography warms the high latitudes





... but applying a high latitude cooling to the run without orography (COOL), does not recreate the CONTROL state. Direct orographic effects are important.

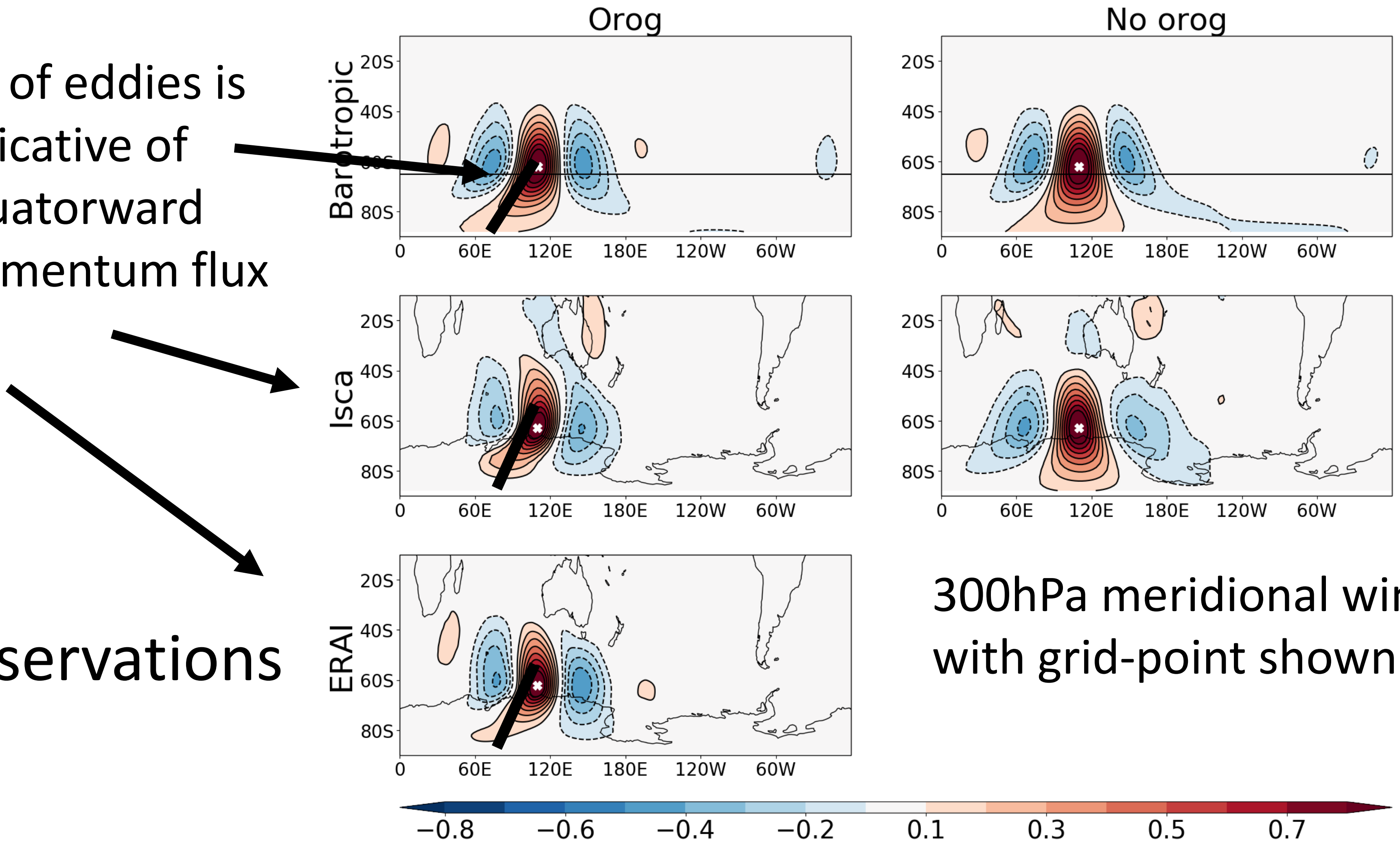
Downstream development from the Indian Ocean



Lagged correlations of meridional wind on the 300hPa (colours) and 850hPa (contours) levels with 300hPa meridional wind at the grid-point shown by the white cross.

Orography affects the propagation of waves

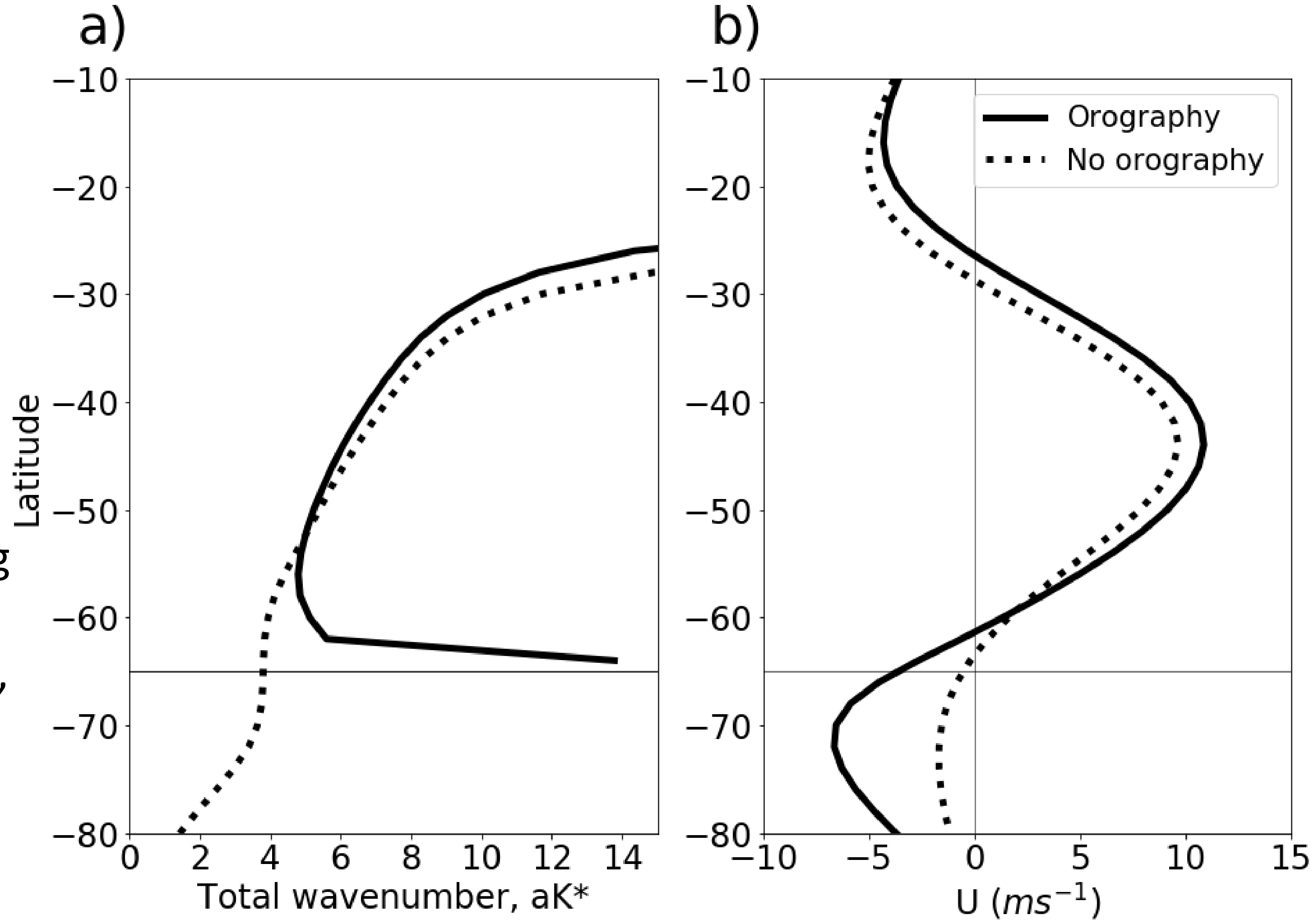
Tilt of eddies is indicative of equatorward momentum flux



Observations

300hPa meridional wind correlations with grid-point shown by white cross

Wave propagation differs between the two runs



Waves experience a turning latitude in the run without bottom orography (dotted), while they reach a critical latitude in the run with orography.