Jet formation in multi-layer fluid over topography

Chiara Stanchieri[1], Joseph H. Lacasce[2], Hennes Hajduk[2], Michiel L.J. Baatsen[1], Henk A. Dijkstra[1]

[1] Utrecht University (IMAU), Netherlands, [2] University of Oslo, Norway

Sharing is encouraged

❖ **Introduction:** The Antarctic Circumpolar Current (ACC) has three distinct surface density fronts, with associated zonal jets. These jets are unstable, meandering and generating eddies. They are also baroclinic, and intensified at the surface. Jets play a central role in ocean dynamics.

❖ **Research Questions:** How do the jets form, and how does bottom topography modify their vertical and horizontal structure?

❖ **Methods:** Solve multi-layer quasi-geostrophic equations on a beta plane using GeophysicalFlows[2], a model coded in Julia. Two- and three-layer (2L, 3L) cases are studied, with a zonal mean flow imposed in the uppermost layer. The topography is a monochromatic sinusoidal function with a varying amplitude (Fig. 2).

➡ 3L parameters are chosen such that the largest eigenvalue is the same as in 2L.

➡ Run the model to equilibrium and study the 2D kinetic energy spectrum for different configurations. For comparison, we plot the arrest "dumbbells", which divide turbulent and wavelike scale[3]. In figures 4 and 6, these are indicated in red.

❖ **Results:** Figures 4 and 6 show representative 2L and 3L cases. The topography has wavenumbers (10,20).

	2L	3L
Flat bottom (not shown)	Jets formation in all layers, and are nearly barotropic.	
Large topography	The flow is topographically locked, and jets don't form in any layers.	The third layer decouples: jets form in the first two upper layers, while the last layer is topographically lock.

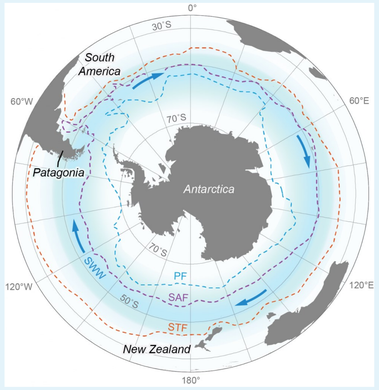

Figure 1: Westerly winds and ocean fronts around Antarctica[1].

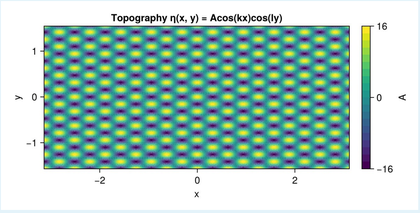

Figure 2: Topography with amplitude A = 16. k=10, l=20.

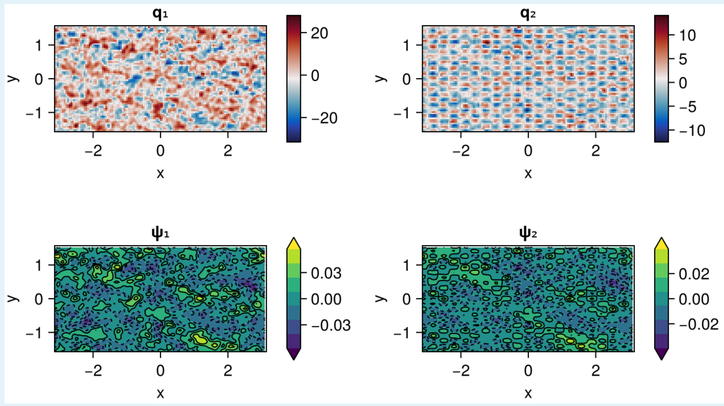

Figure 3: Potential vorticity **(q)** and streamfunction (**ψ**) for the 2L case with topography.

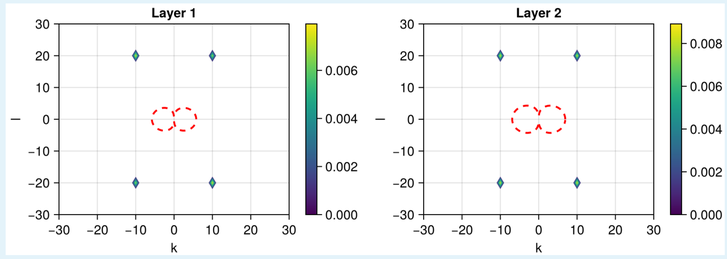

Figure 4: Energy spectrum (diamonds) and Rhines scale (red dumbbells) in 2L case with topography. The energy is concentrated around the topographic wavenumbers (10,20).

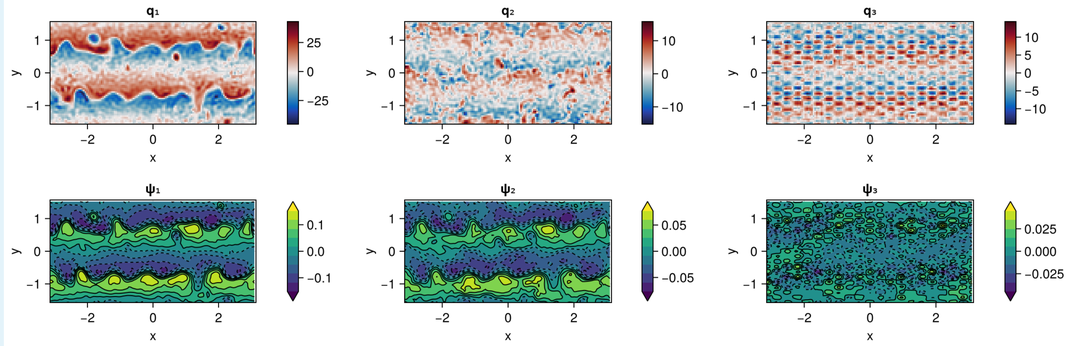

Figure 5: Potential vorticity **(q)** and streamfunction (**ψ**) for the 3L case with topography.

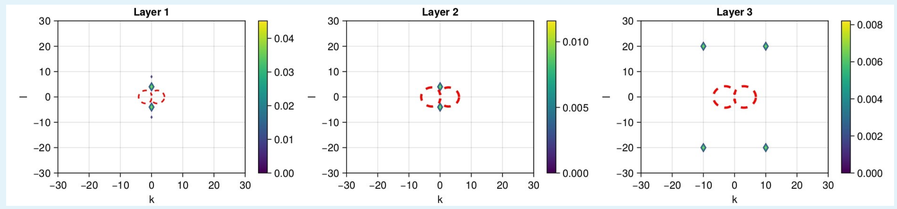

Figure 6: Energy spectrum and Rhines scale in the 3L case with topography. In the first two layers, jets are represented by the diamonds at k=0, meaning they cover the whole domain in the x-direction.

❖ **Conclusion:** Bottom topography plays a key role in jet formation, as it restricts their development to the upper ocean. Increasing vertical resolution enables layer decoupling and potentially a more accurate description of jets. In the 2-layer model, topography hinders jets formation, while in the 3-layer model, topography decouples the abyss allowing jets formation in the upper ocean.

This presentation participates in OSPP

Outstanding Student & PhD candidate Presentation contest

References:

[1] Southern Annular Mode - AntarcticGlaciers.org

[2] Navid C. Constantinou et. al. GeophysicalFlows.jl: Solvers for geophysical fluid dynamics problems in periodic domains on CPUs & GPUs, Journal of Open Source Software, (2021).

[3] Vallis, G., & Maltrud, M. (1993). Generation of mean flows and jets on a beta plane and over topography. Journal of Physical Oceanography,23(7), 1346–1362.

Contact details:
Chiara Stanchieri
c.stanchieri@students.uu.nl
Looking for a PhD
29th April 2025

Abstract, supplementary materials and judging form.