Barotropic versus Baroclinic Eddy Saturation

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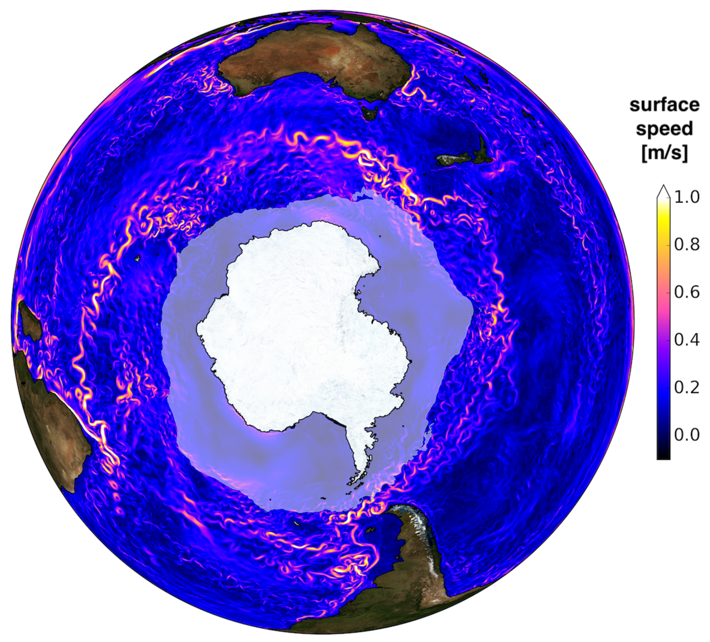
How does the ACC respond to the increasing winds over the Southern Ocean?

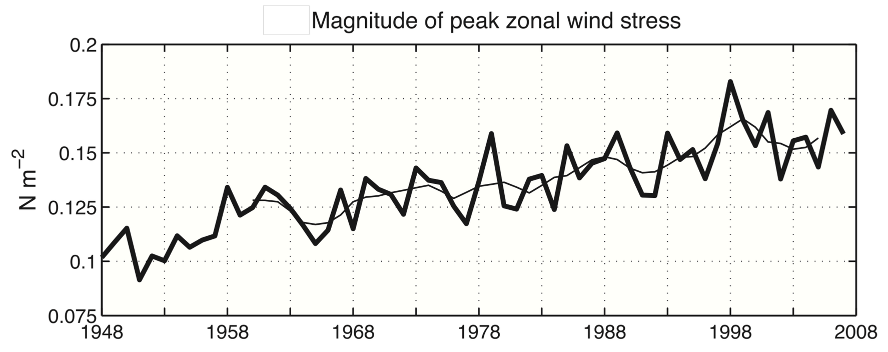
Motivation

The Antarctic Circumpolar Current (ACC) is an important driver of the global climate.



[ACCESS-OM2-010 sea surface speed, COSIMA Consortium]

Westerlies over the Southern Ocean that drive the ACC are getting stronger:



[Farneti et al. 2015]

How will the ACC respond to increasing winds?

"Eddy saturation"

Many models (idealized & realistic) find that:

as the wind strength increases,
the ACC remains (almost) insensitive.

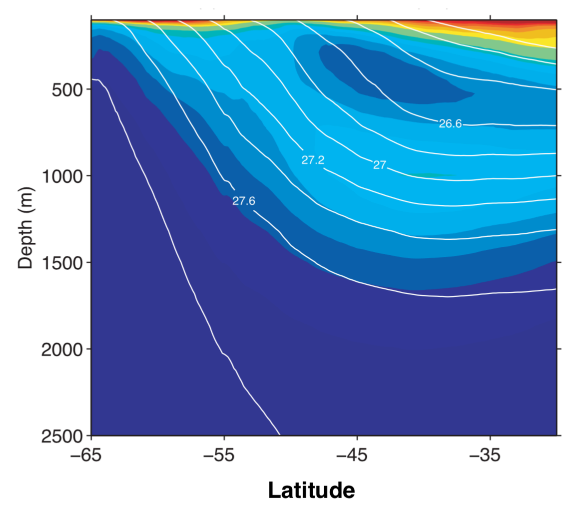
All excess momentum from the wind goes into eddies:

→ "**eddy saturation**"

Traditionally, a flow is "eddy saturated" if the volume zonal transport shows (substantially) less than linear increase with wind stress strength.

The "textbook" explanation is that:

increasing winds → isopycnals slope more → more available potential energy → more eddies produced by baroclinic instability → **the mean flow (ACC) stays the same**



[Meredith et al. 2012]

Barotropic Eddy Saturation

Recently, it was shown that **barotropic** (depth-independent) flow **above bathymetry** can **also** show eddy saturation.

[Constantinou & Young 2017, Constantinou 2018]

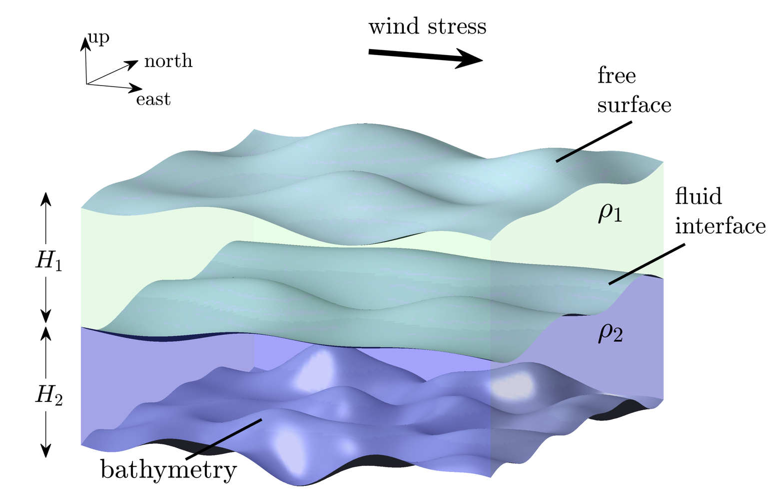
This challenges the current paradigm...

Objectives

Demystify the physics behind eddy saturation:

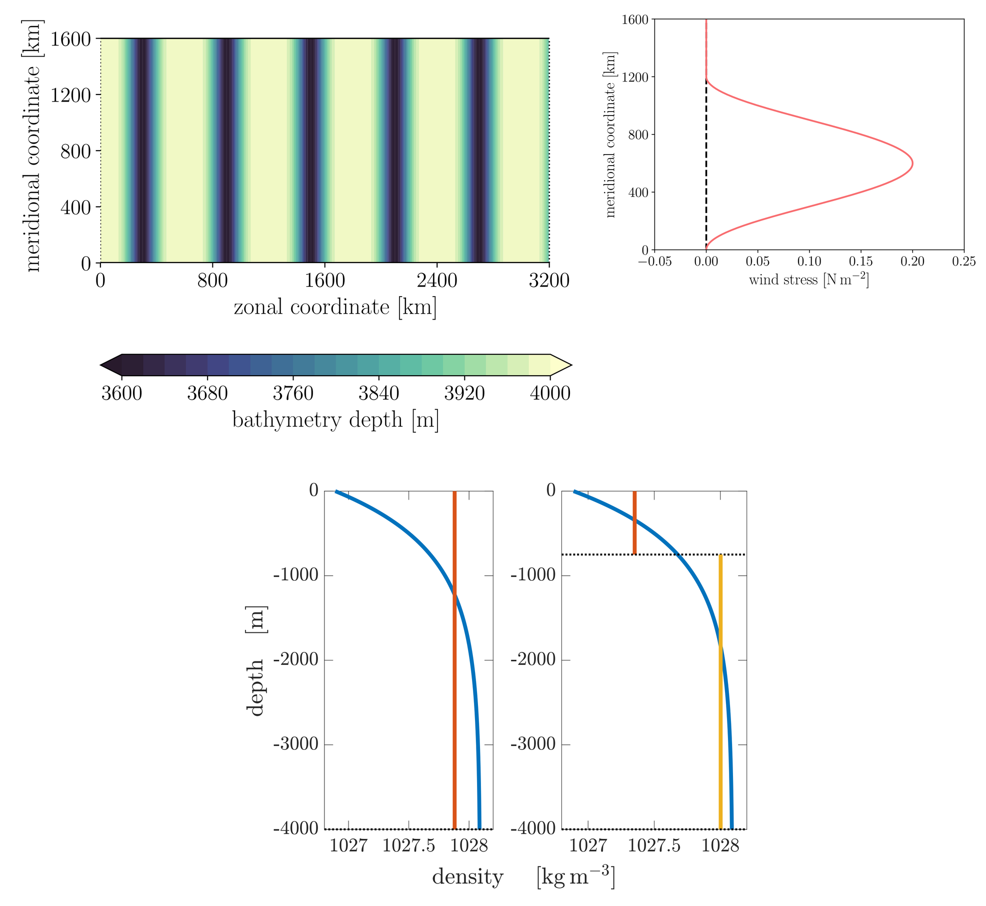
- Establish whether barotropic flows show eddy saturation in a primitive-equation model.
- Assess the relative importance of barotropic and baroclinic processes in the observed eddy-saturated states.

Model



[an example configuration with a two-layer fluid]

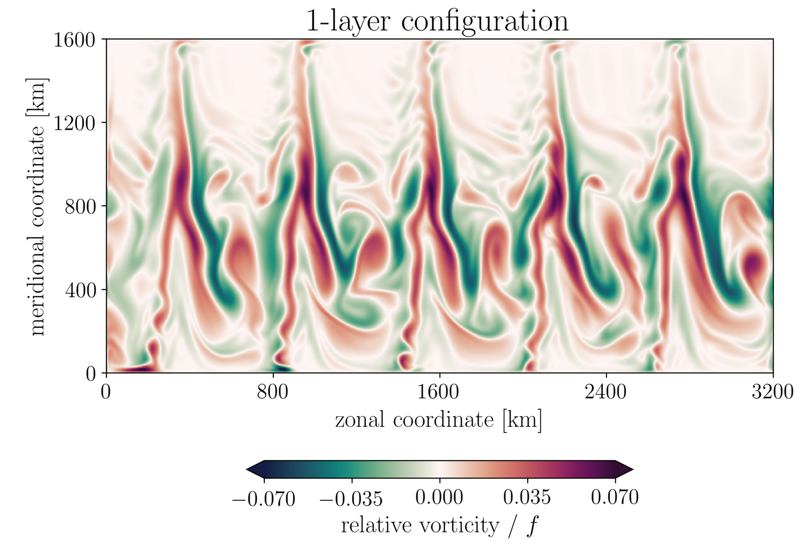
- Idealized re-entrant channel with 'bumpy' bottom
- $L_x = 3200\,\mathrm{km}$, $L_y = 1600\,\mathrm{km}$, and $H = 4\,\mathrm{km}$
- Beta-plane with Southern Ocean parameters
- Modest stratification (few fluid layers of constant ρ)
- 1st Rossby radius of deformation: 15.7 km (for ≥ 2 layers)
- Modular Ocean Model v6 (MOM6) in isopycnal mode

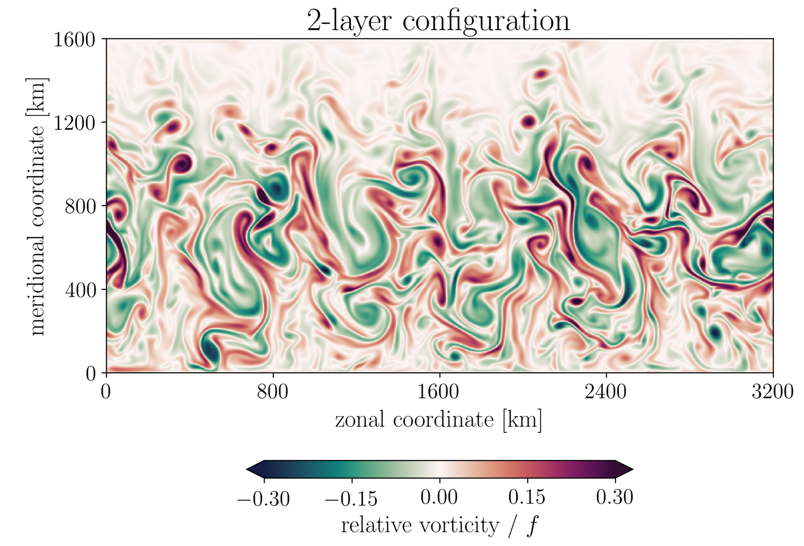


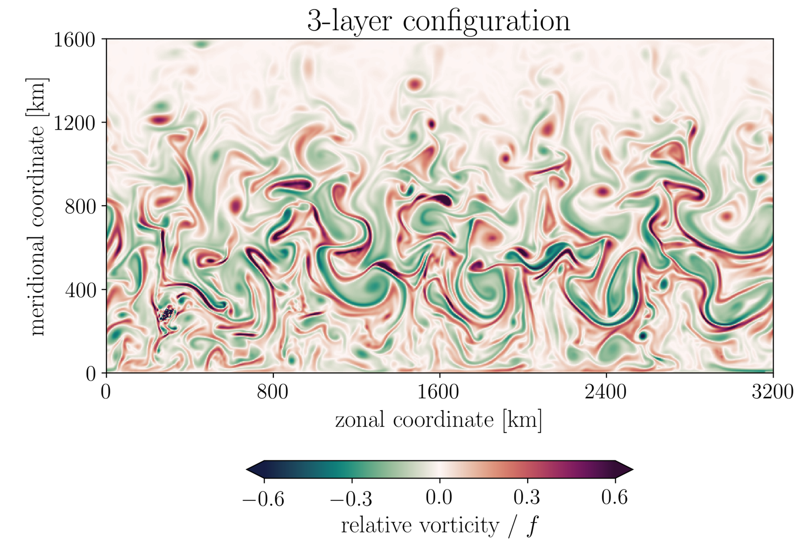
[bathymetry, wind stress, 1- and 2-layer stratification discretizations]

What does the flow looks like?

Vorticity in the top-fluid layer for wind stress peak 0.5 N m^{-2}:

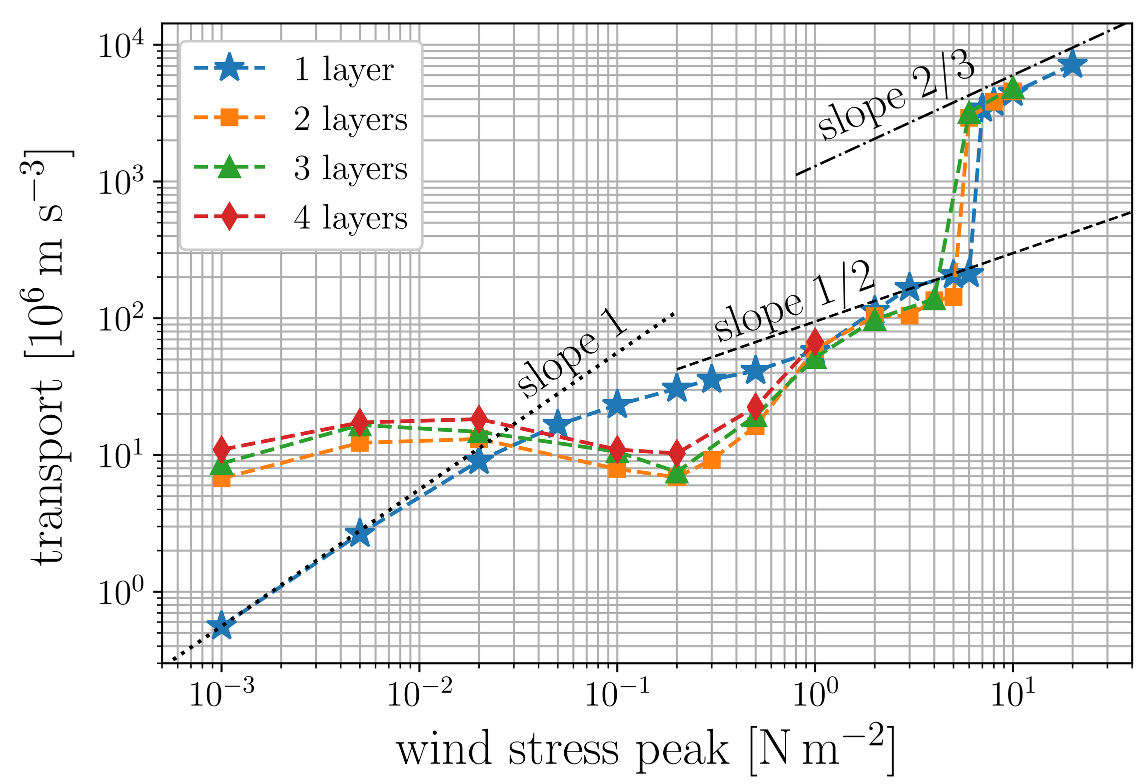






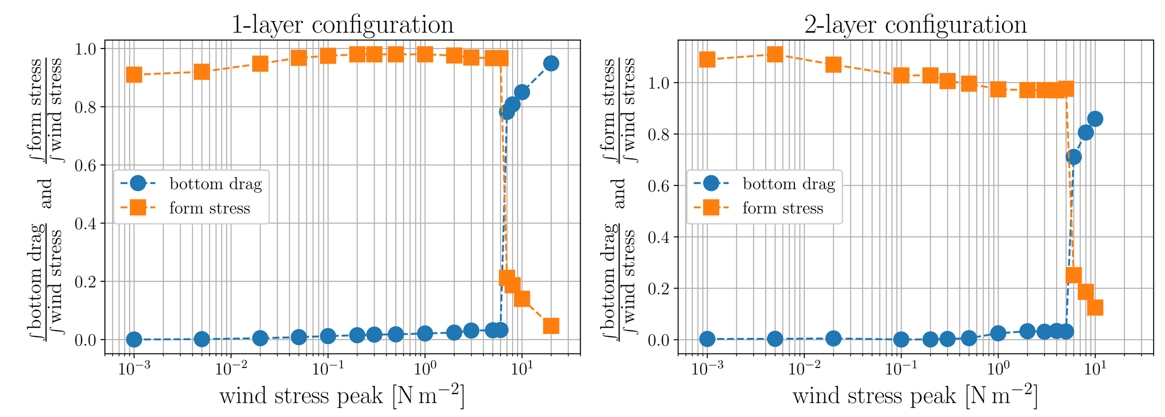
The 1-layer fluid configuration shows eddies. These eddies do not result from baroclinic instability.

How transport varies with wind stress?

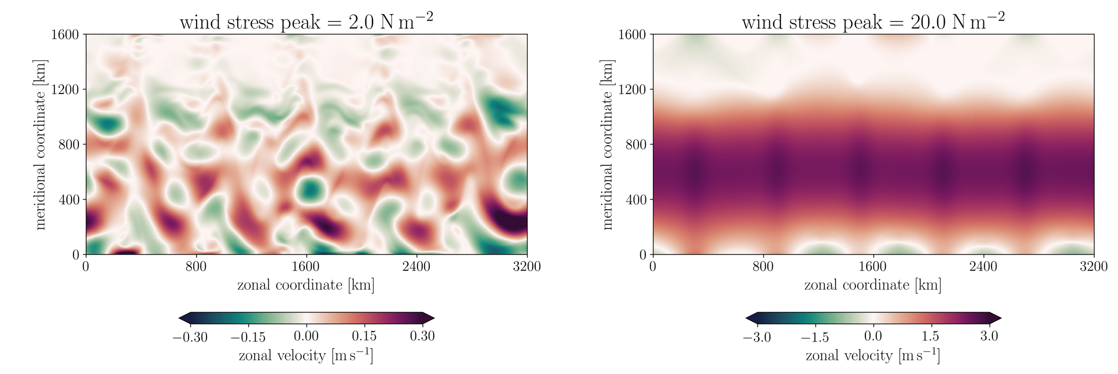


- Baroclinic cases (# layers ≥ 2) show an eddy saturation regime.
- The single-layer case (barotropic) shows insensitivity to wind stress (transport grows only about 10-fold over 100-fold wind stress increase)

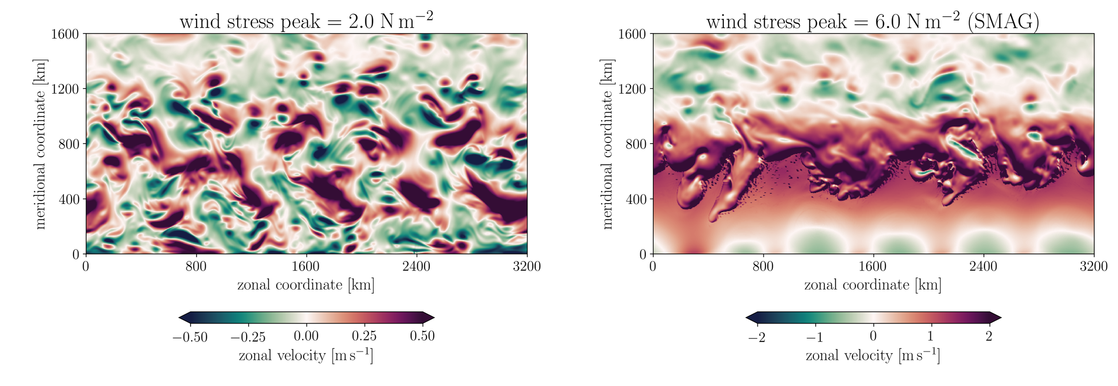
What balances the wind stress?



- Most of the momentum is balanced by bottom form stress.
- The flow shows a transition to a regime with high transport and in which the momentum balance changes. (Consistent with Constantinou & Young 2017, Constantinou 2018)



[zonal flow structure for 1-layer setup]



[top-layer zonal flow structure for 2-layer setup]

Conclusions

- There exists a barotropic contribution to eddy saturation (e.g., for 0.05 < wind stress < 1.00).
- The barotropic eddy saturation relies on eddy production due to bathymetric features.
- This highlights the role of topographically-induced eddies.
- At high wind stress values there is a structural bifurcation to a strong zonal flow that does not "see" the topography.

References

Constantinou & Young (2017) Beta-plane turbulence above monoscale topography. *J. Fluid Mech.*, **827**, 415-447.

Constantinou (2018) A barotropic model for eddy saturation. *J. Phys. Oceanogr.*, **48 (2)**, 397-411.

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