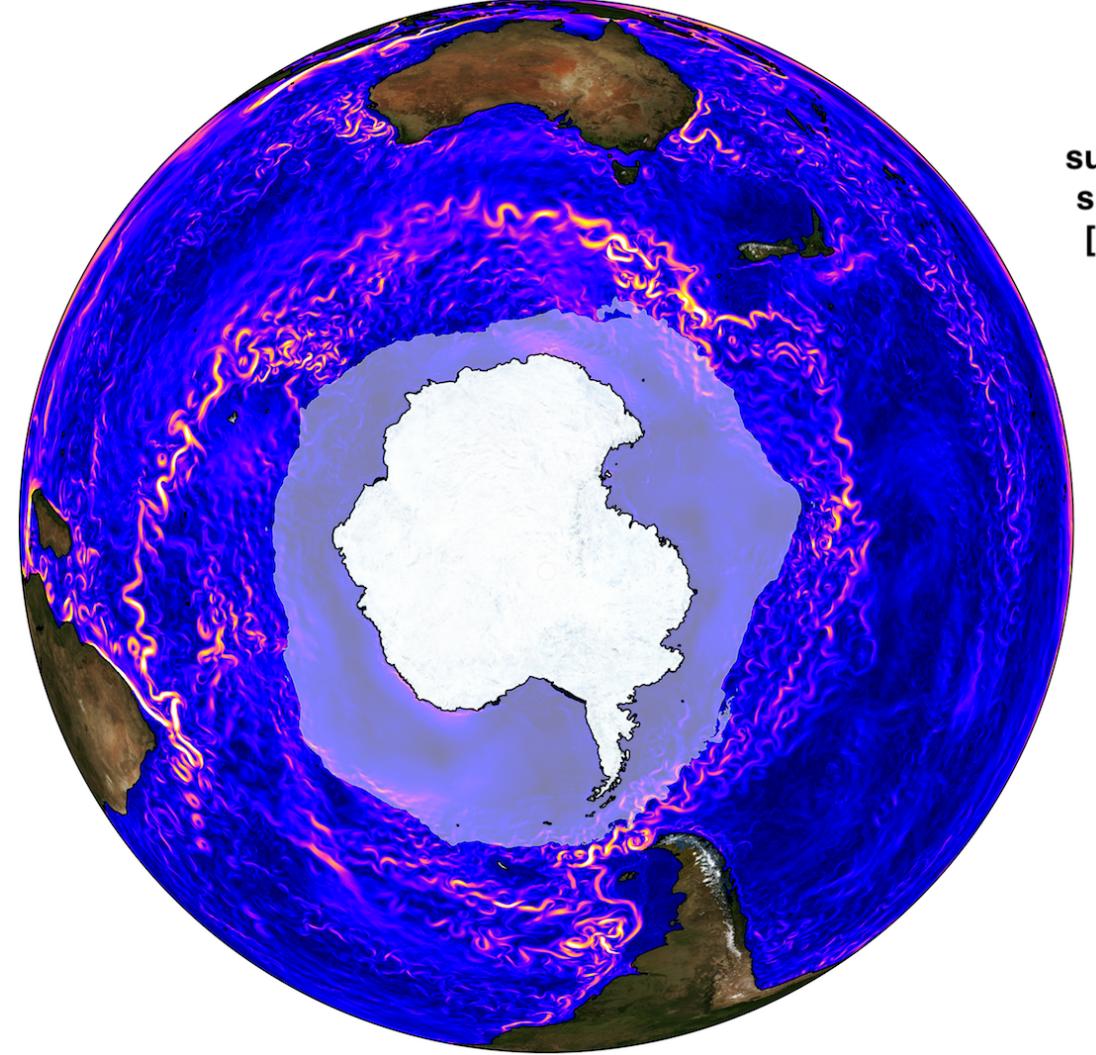


How does the Antarctic Circumpolar Current respond to the increasing winds over the Southern Ocean?

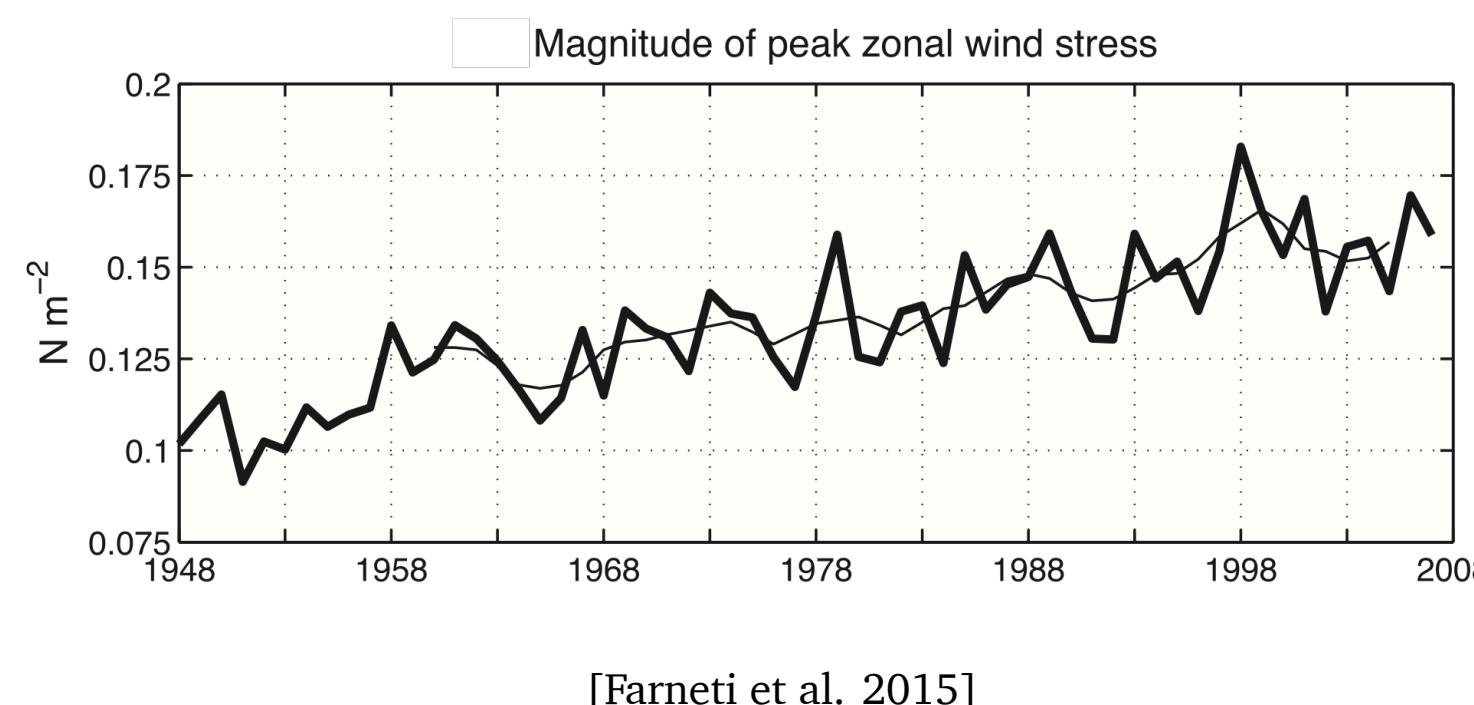
Motivation

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:



How will the ACC respond to increasing winds?

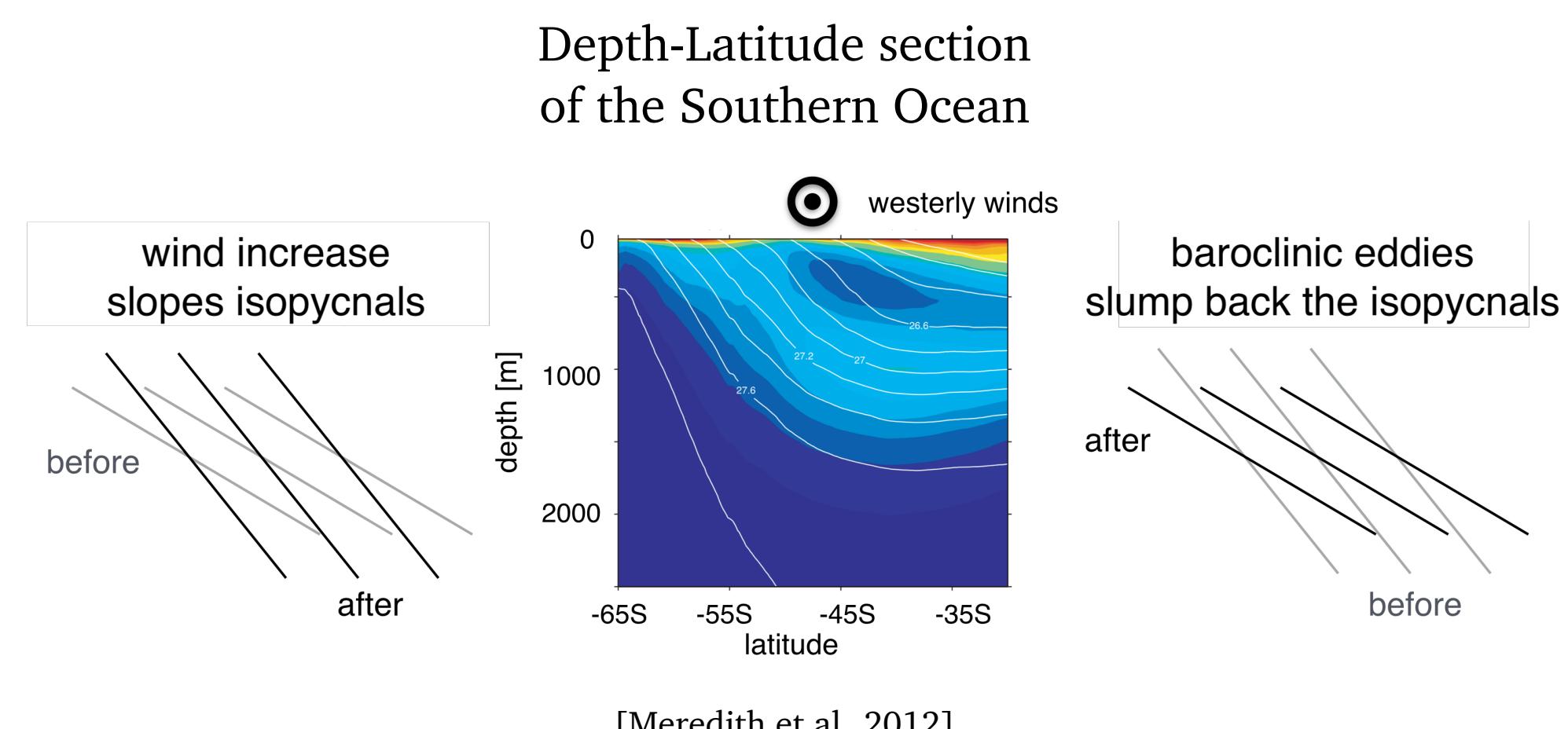
Eddy saturation

Many models (idealized & realistic) find that:

wind strength increases → ACC remains (almost) insensitive.

Excess momentum from the winds goes into eddies: “eddy saturation”

Textbook interpretation based on baroclinic instability



Eddies tap the excess energy due wind increase → ACC stays the same

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...

Barotropic Eddy Saturation

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

[Constantinou & Young 2017, Constantinou 2018]

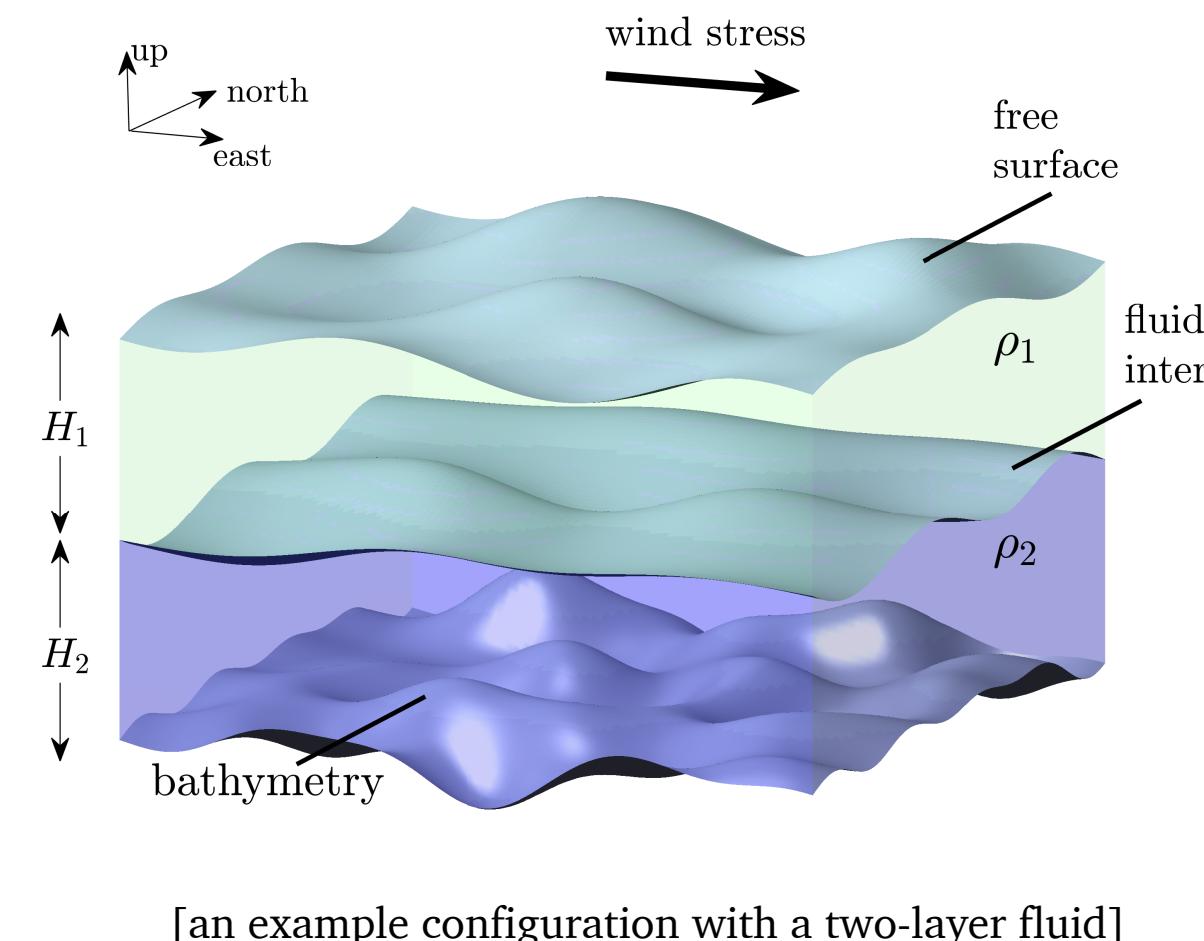
This challenges the current paradigm...

Objectives

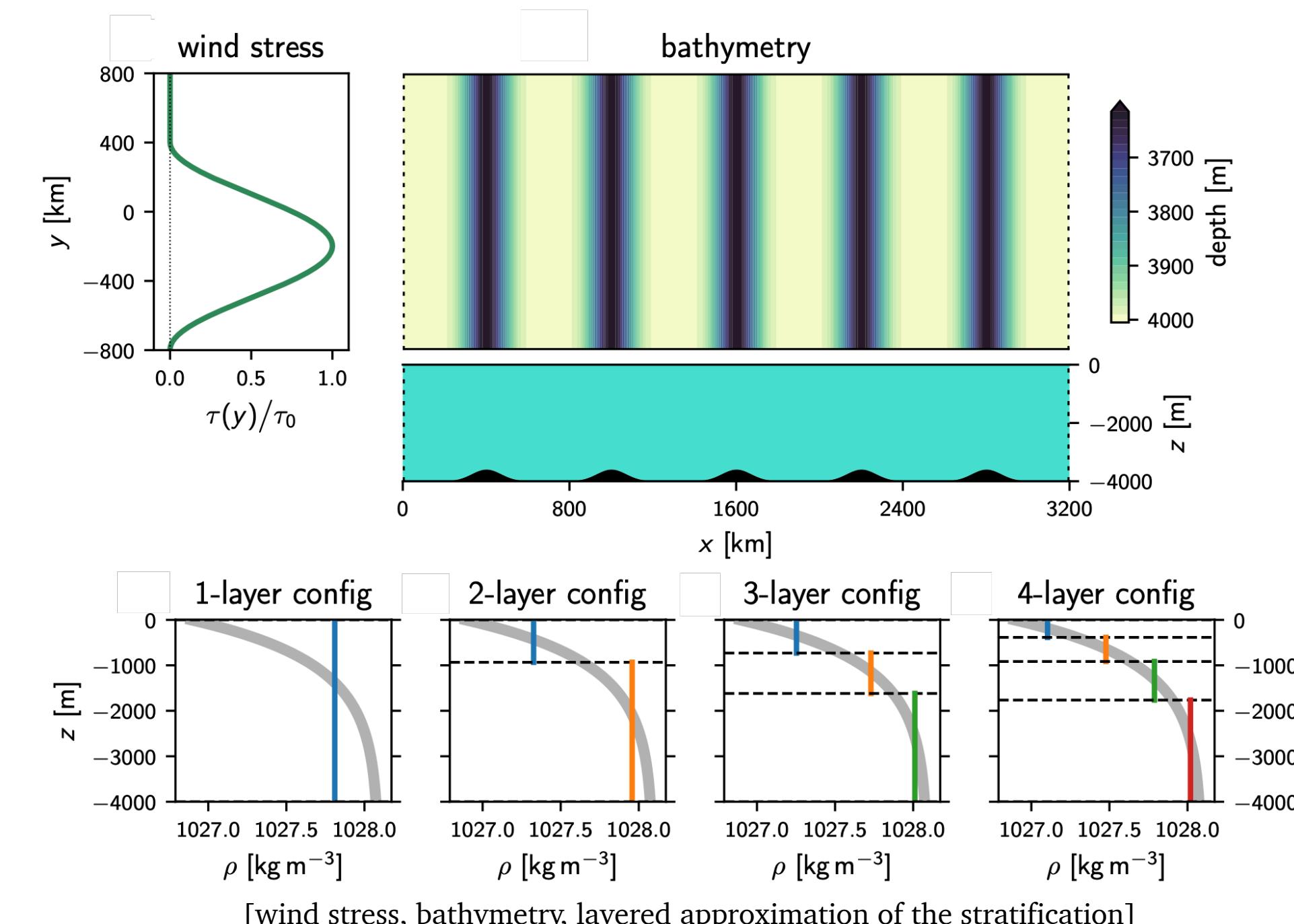
Demystify the physics behind eddy saturation:

- 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

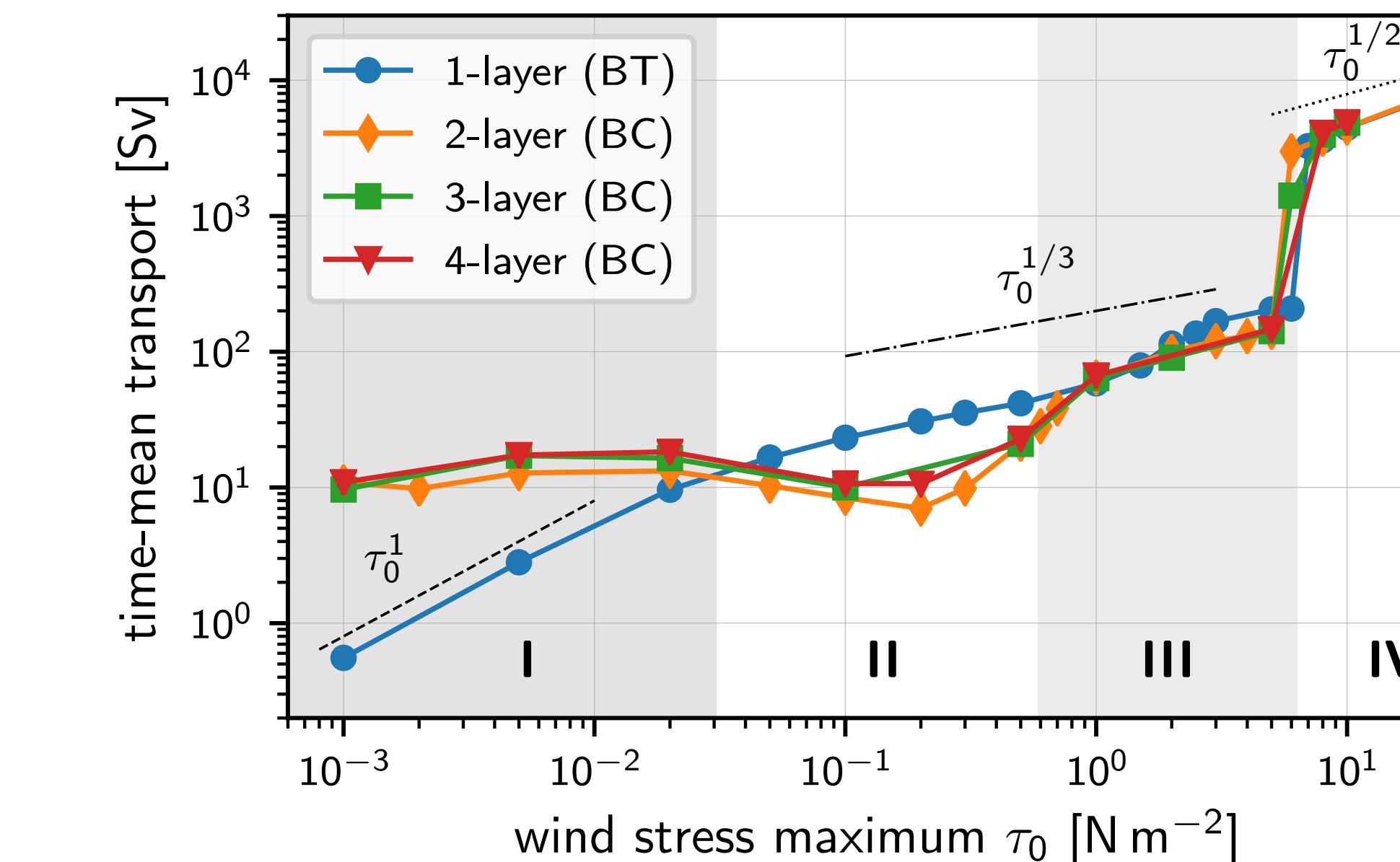


- Idealized re-entrant channel with ‘bumpy’ bottom
- $L_x = 3200$ km, $L_y = 1600$ km, and $H = 4$ km
- Beta-plane with Southern Ocean parameters
- Modest stratification (few fluid layers of constant ρ)
- 1st Rossby radius of deformation: 15.7 km (for ≥ 2 layers)
- Modular Ocean Model v6 (MOM6) in isopycnal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



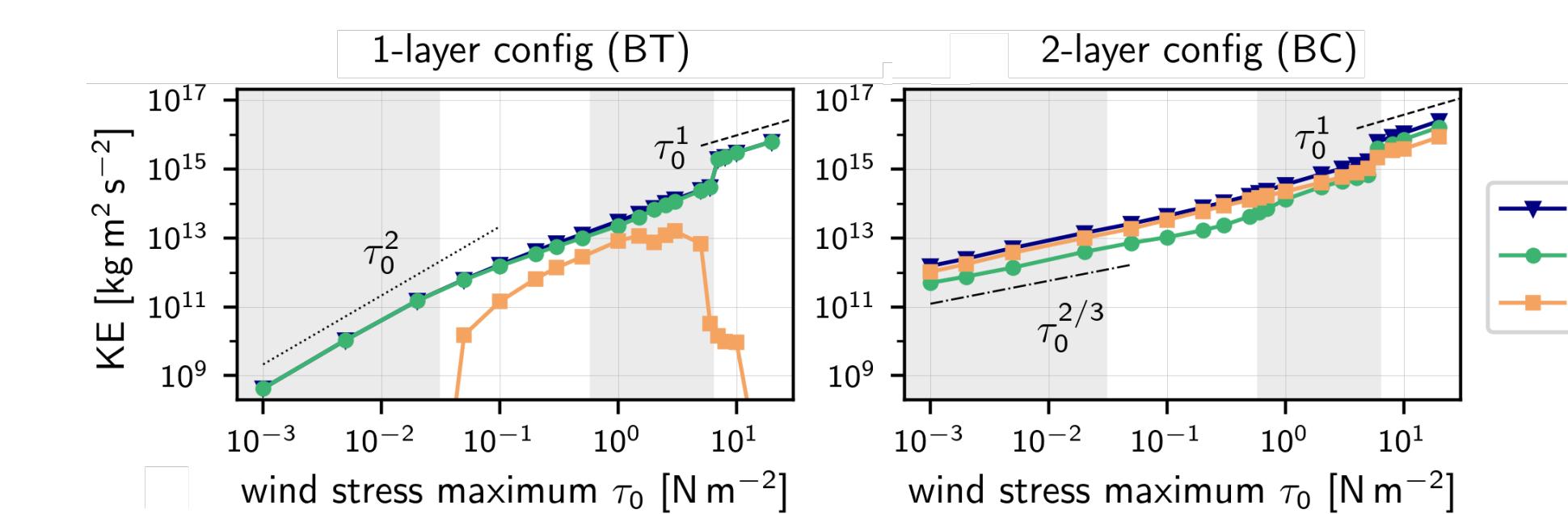
Eddies tap the excess energy due wind increase → ACC stays the same

How transport scales with wind stress?



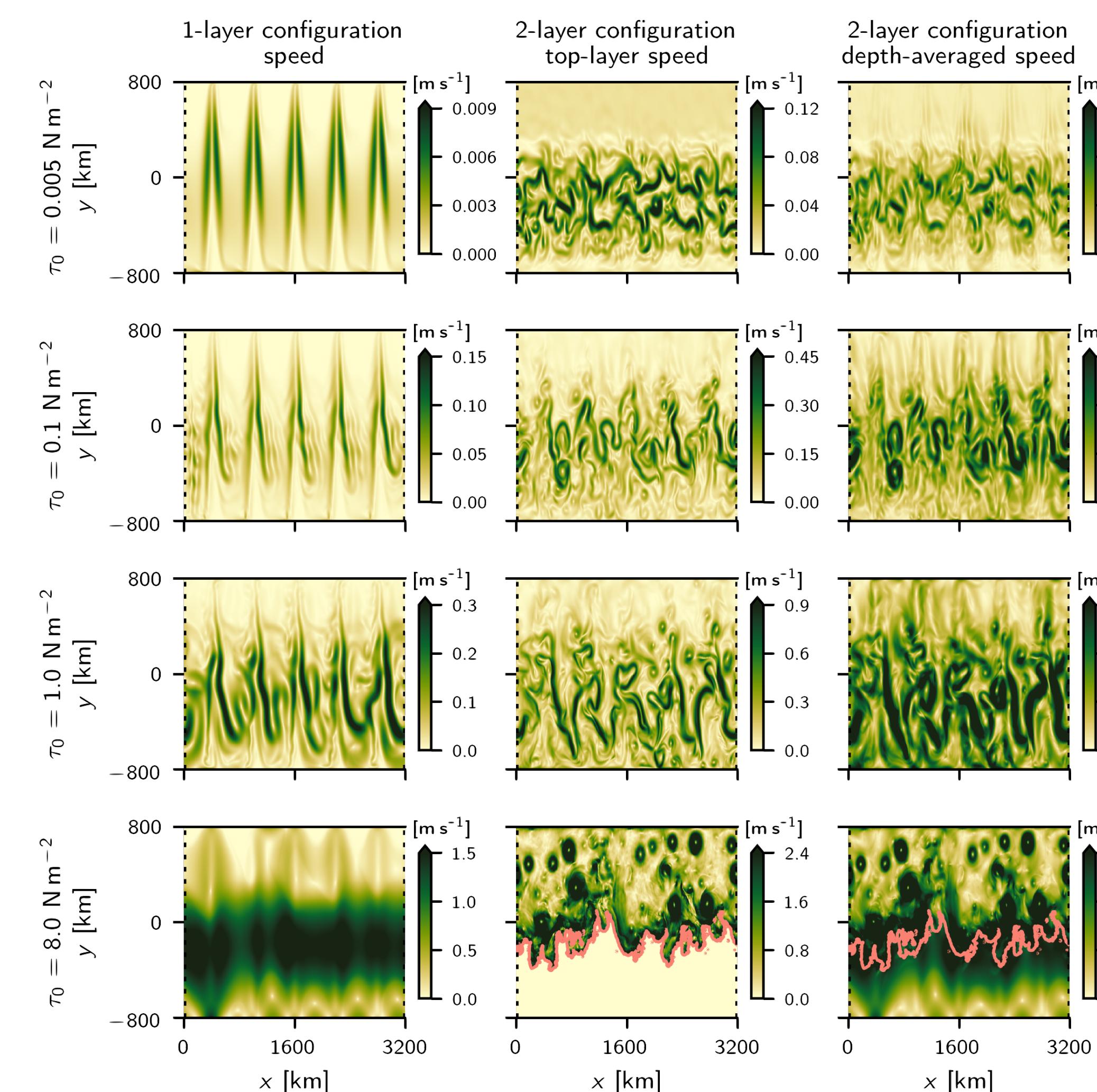
- Four distinct flow regimes.
- Baroclinic cases (# layers ≥ 2) show an eddy saturation regime.
- The single-layer case (barotropic) shows insensitivity to wind stress (transport grows only about 10-fold over 100-fold wind stress increase)

Which flow regimes show transient eddy activity?



What does the flow look like?

Top-view snapshots for 1-layer (BT) and 2-layer (BC) configs:

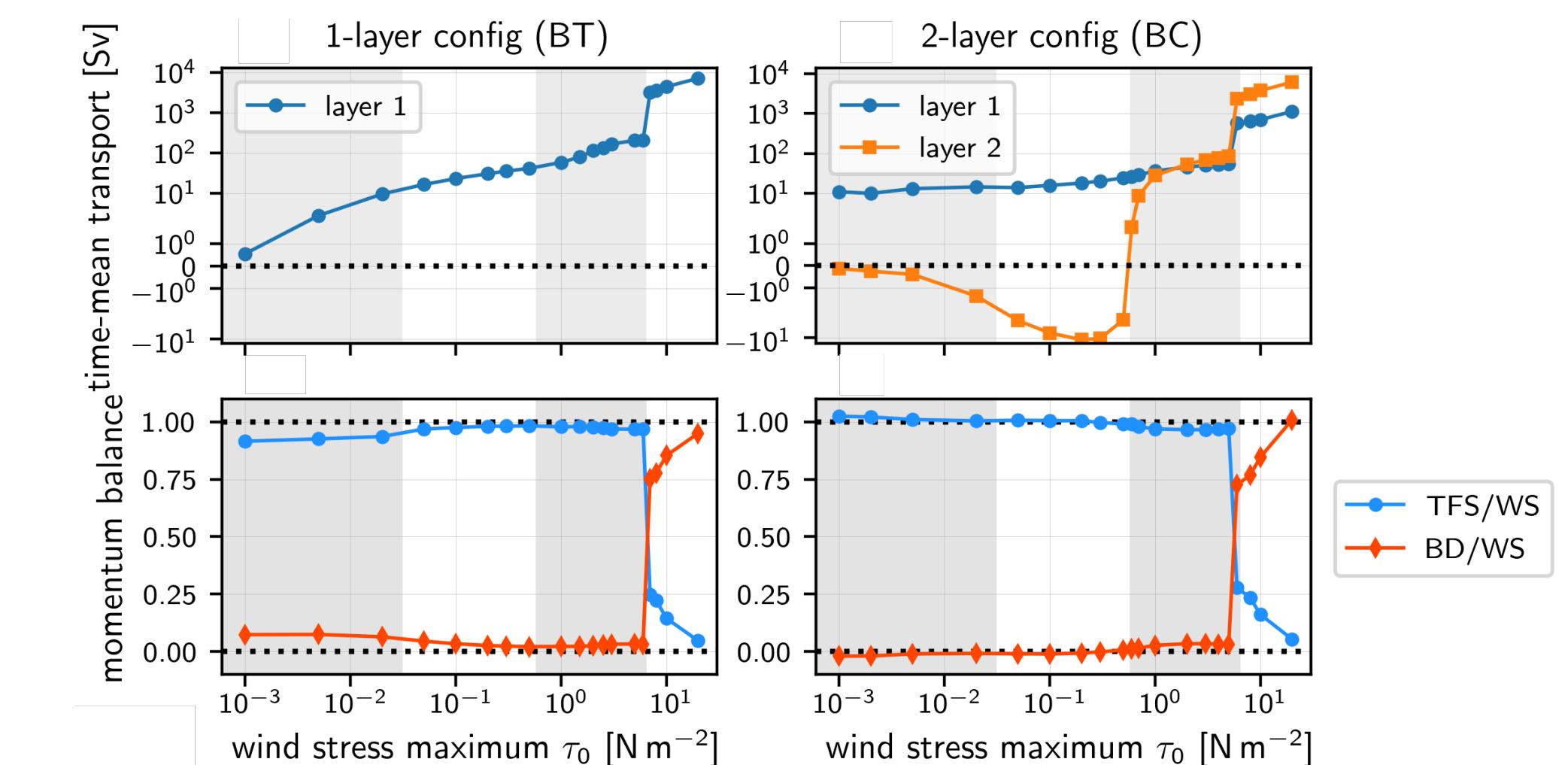


The 1-layer fluid configuration shows eddies. These eddies do not arise from baroclinic instability.

What balances the wind stress?

$$\langle \tau \rangle = \langle \overline{p_{\text{bot}} \partial_x h_{\text{bot}}} \rangle + \langle \rho_m c_D |\mathbf{u}_n| u_n \rangle$$

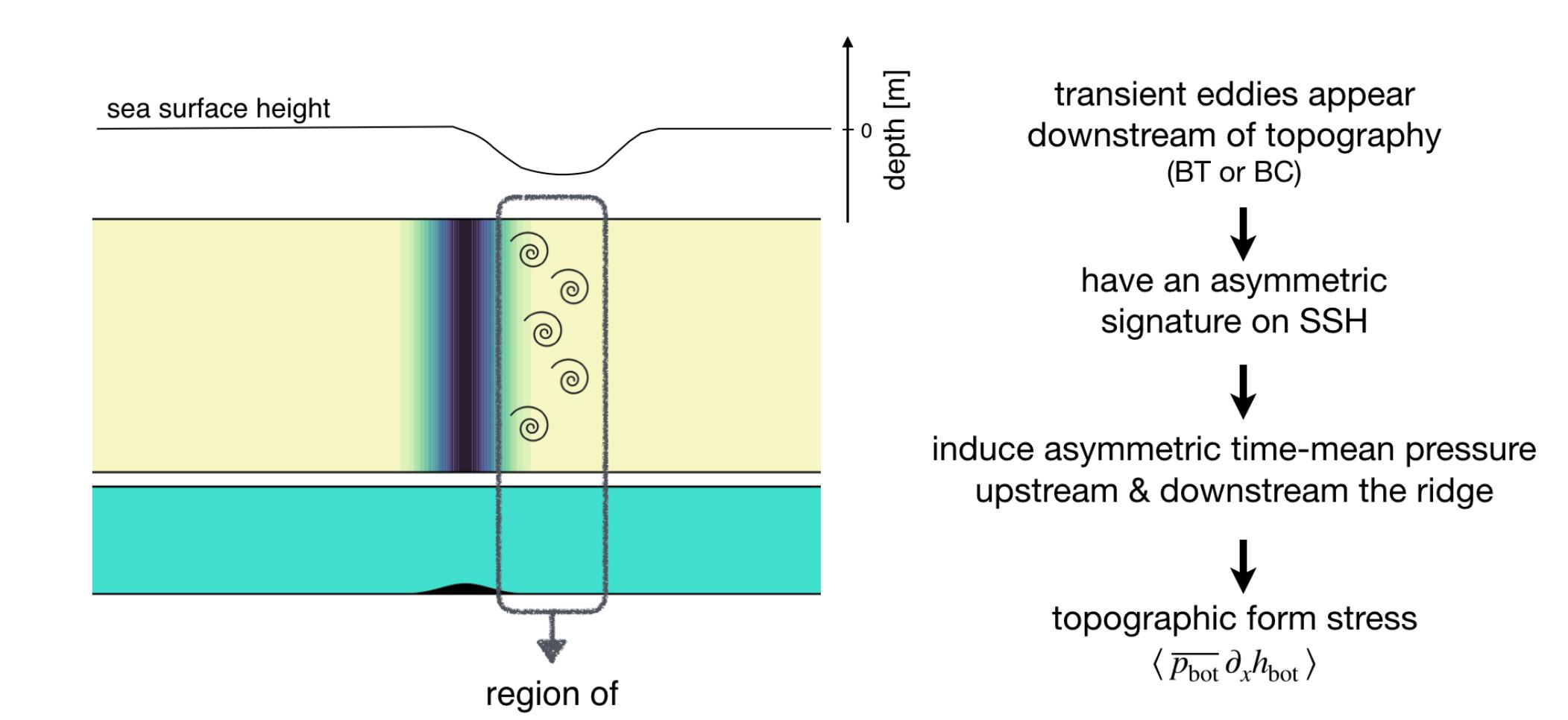
wind stress (WS) form stress (TFS) bottom drag (BD)



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

How transient eddies affect mean momentum balance?

Transient eddies affect the momentum balance.
But transient eddies do not appear in TFS: $\langle \overline{p_{\text{bot}} \partial_x h_{\text{bot}}} \rangle = \langle \overline{p_{\text{bot}} \partial_x h_{\text{bot}}} \rangle$



Conclusions

- There exists a barotropic contribution to eddy saturation (e.g., for $0.05 < \text{wind stress} < 1.00$).
- Barotropic eddy saturation relies on eddy production due to bathymetric features or lateral shear instabilities.
- 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.

Proposal

Eddy saturation results from the feedbacks between transient eddies and the mean flow that create topographic form stress and, in turn, balances the momentum input from wind stress.

This occurs regardless of the process from which the transient eddies originate.

References

- Constantinou & Hogg (2019) *GRL*, 46, 12202–12212.
Constantinou (2018) *JPO*, 48 (2), 397–411.
Constantinou & Young (2017) *JFM*, 827, 415–447.