



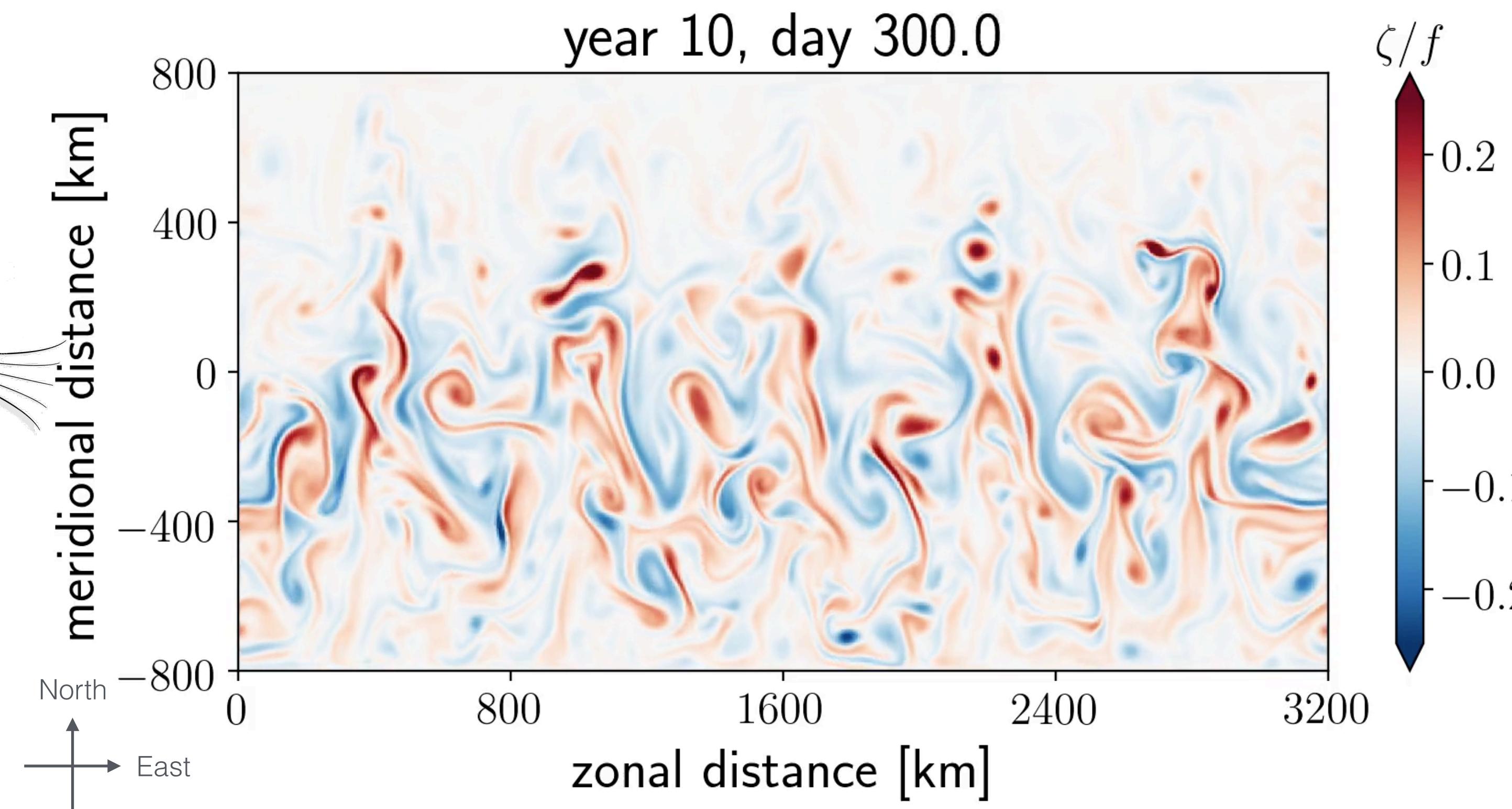
Australian National
University

Barotropic versus Baroclinic eddy saturation: implications to Southern Ocean dynamics

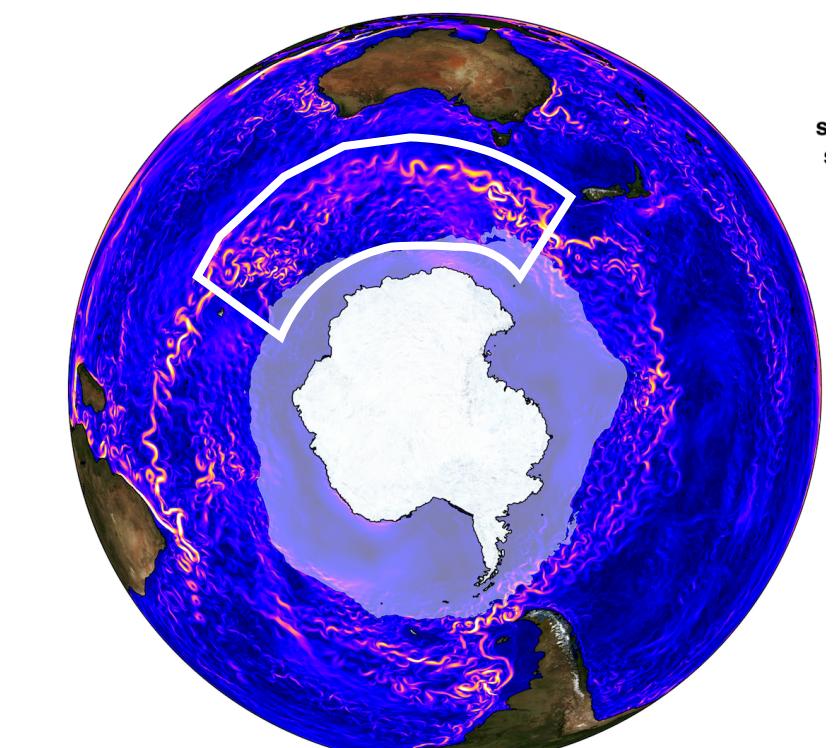


ARC Centre of Excellence
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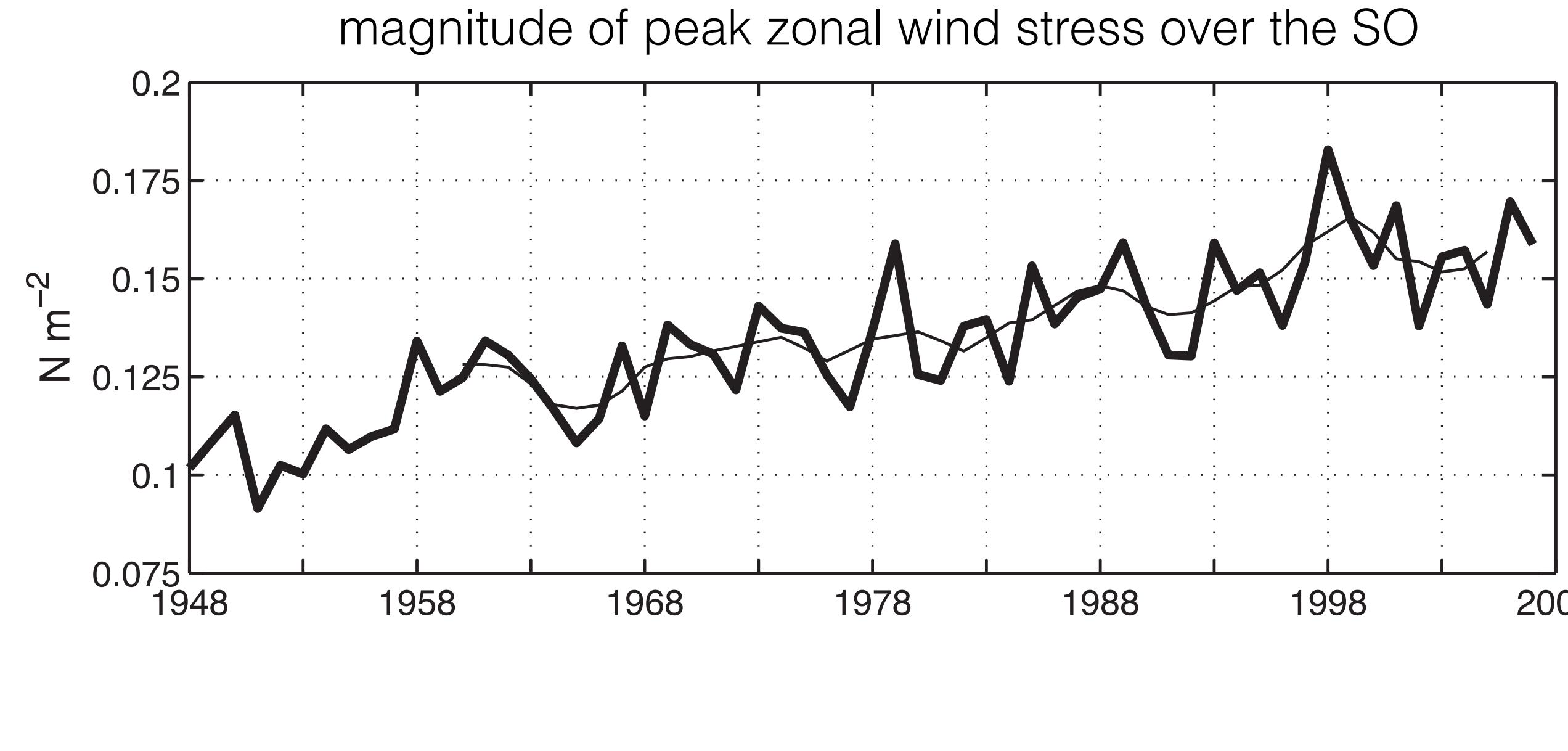
Navid Constantinou & Andy Hogg



top-layer
relative vorticity
 $\zeta = \partial_x v - \partial_y u$



winds over Southern Ocean are getting stronger

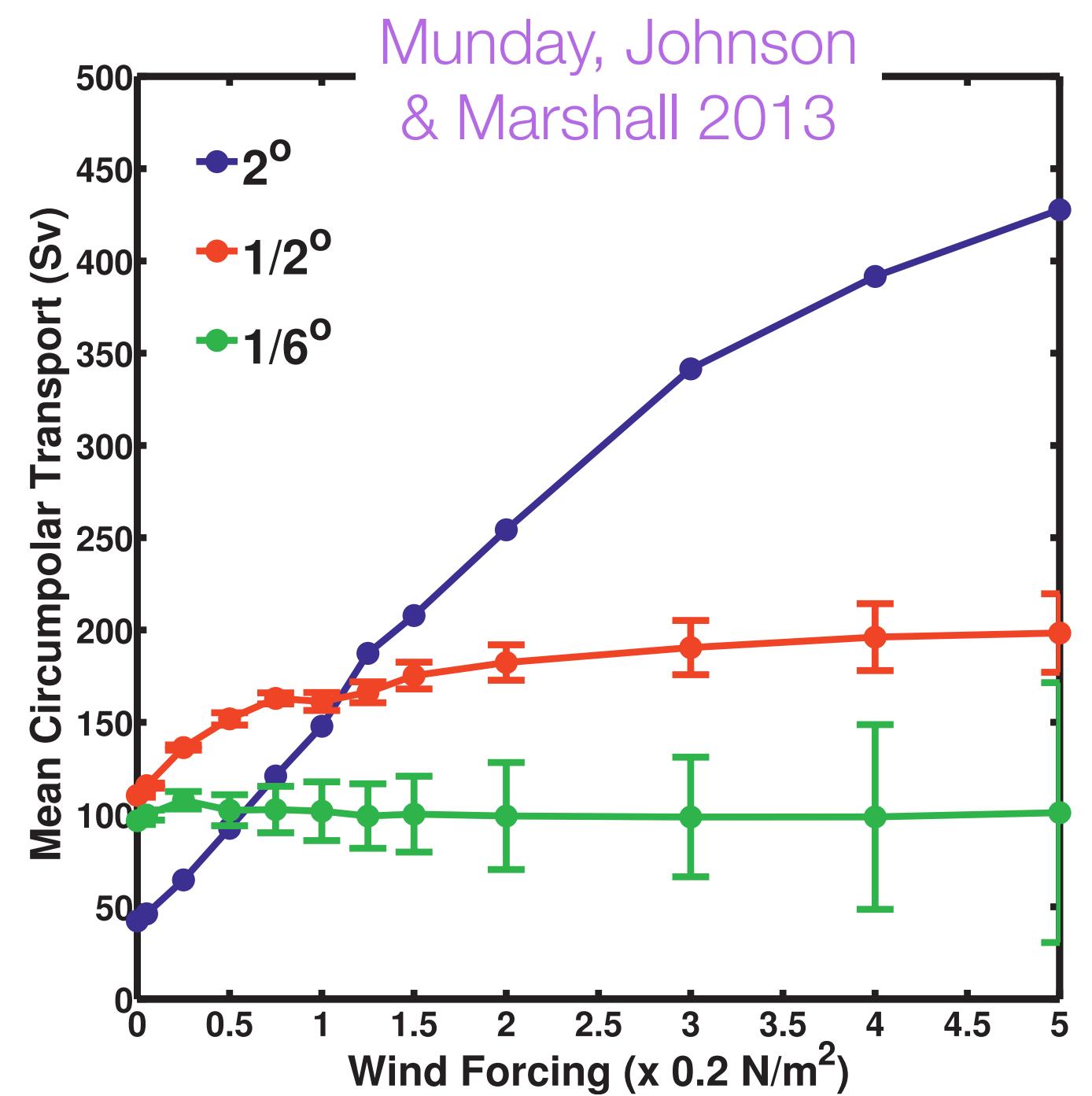


how will the Antarctic Circumpolar Current (ACC) respond?

does doubling the winds imply double ACC the transport?
not always — “eddy saturation”

what's eddy saturation?

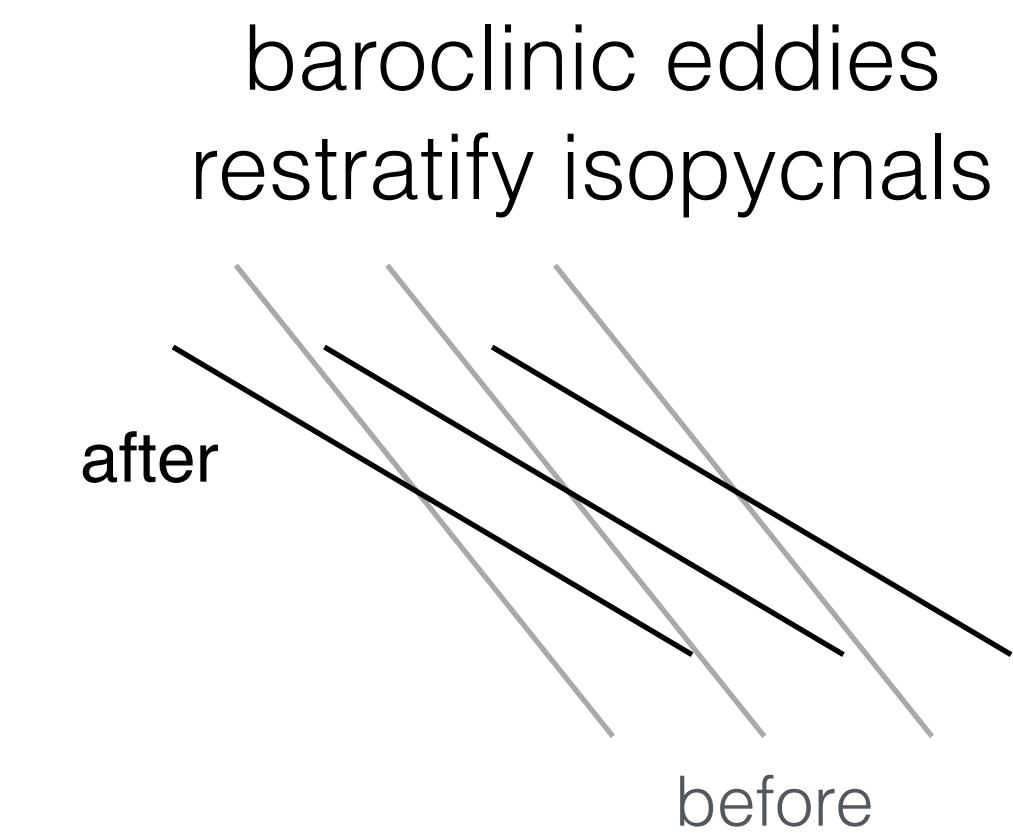
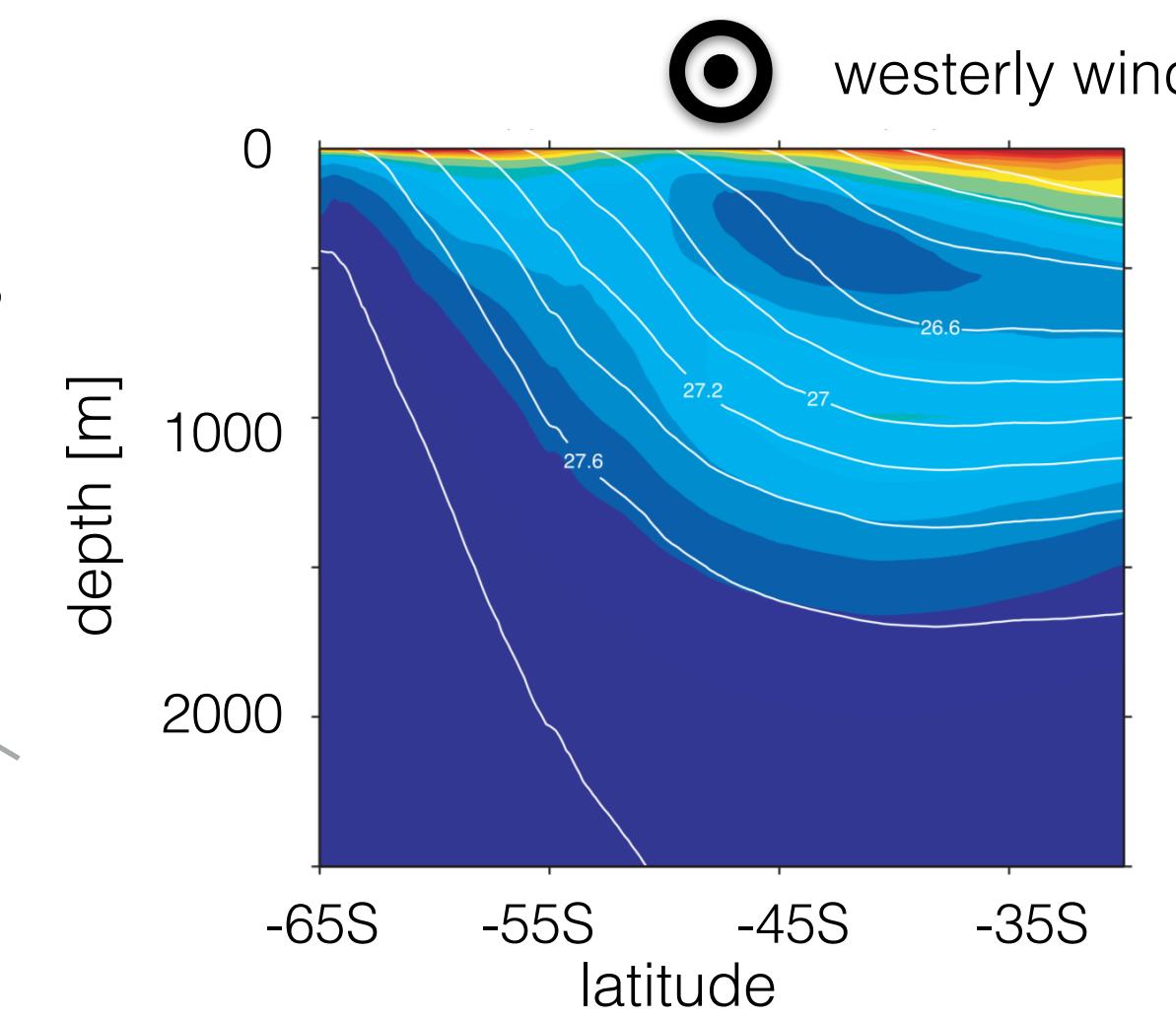
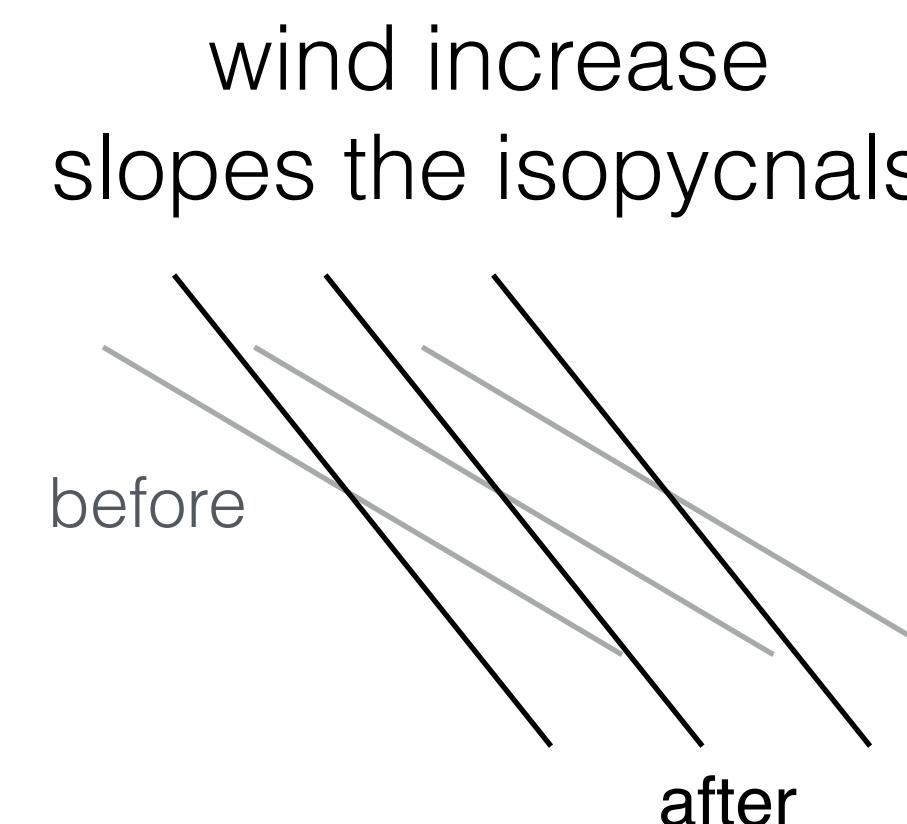
The *insensitivity* of the time-mean ACC volume transport to wind stress increase.



higher resolution → eddy saturation “occurs”

Eddy saturation is seen in eddy-resolving ocean models.
(some hints also in obs.)

Eddy saturation was theoretically predicted by Straub (1993)
but with an *entirely baroclinic* argument.



[Other examples: Hallberg & Gnanadesikan 2001, Tansley & Marshall 2001, Hallberg & Gnanadesikan 2006, Hogg et al. 2008, Nadeau & Straub 2009, 2012, Farneti et al. 2010, Meredith et al. 2012, Morisson & Hogg 2013, Abernathey & Cessi 2014, Farneti et al. 2015, Nadeau & Ferrari 2015, Marshall et al. 2017.]

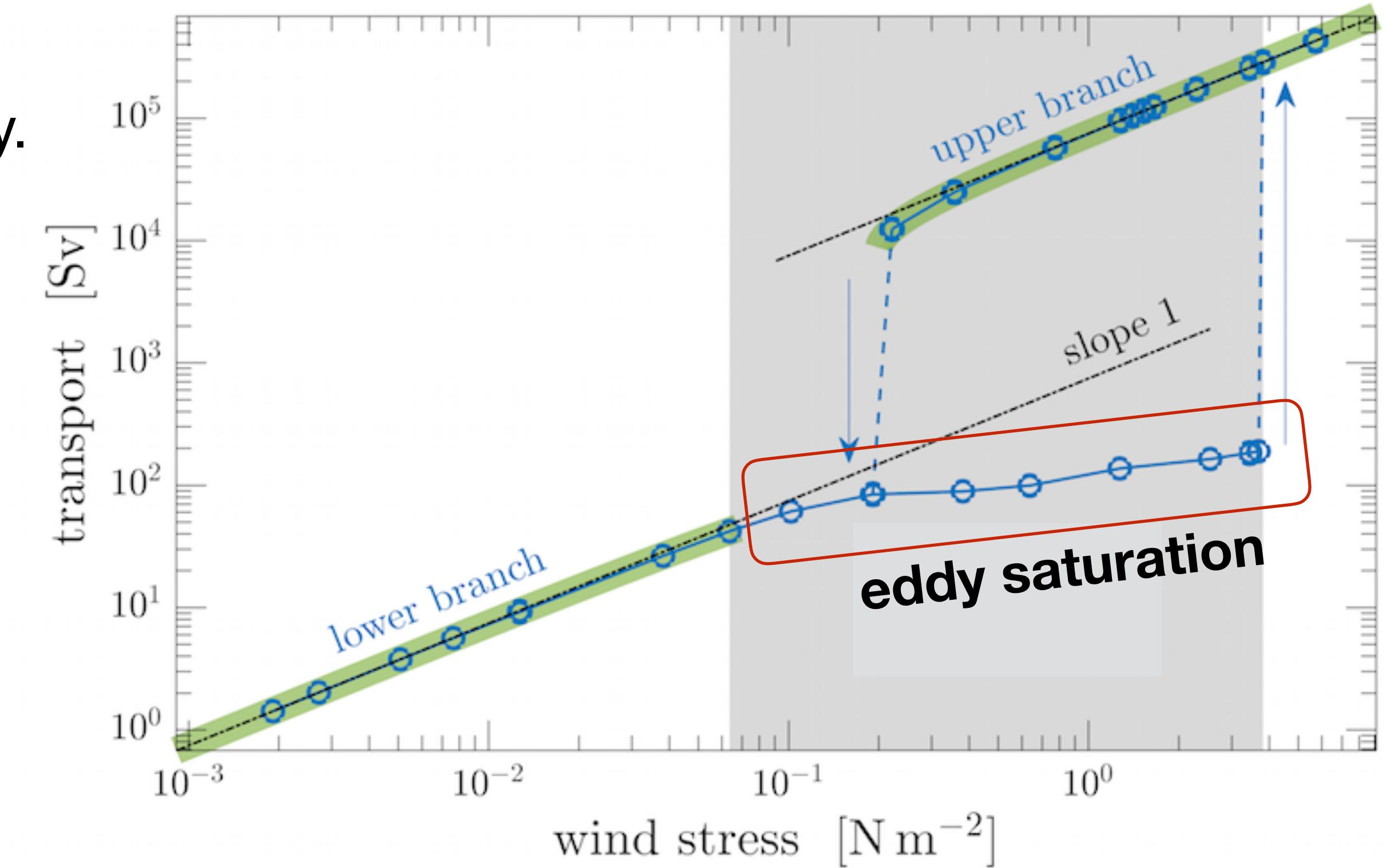
in the previous episode

[back in 2017, in a Portland far far away]

Eddy saturation can occur *without* baroclinicity
in a homogeneous QG barotropic model with bathymetry.

Surprising!

All previous arguments *relied* on baroclinic instability
for producing transient eddies.



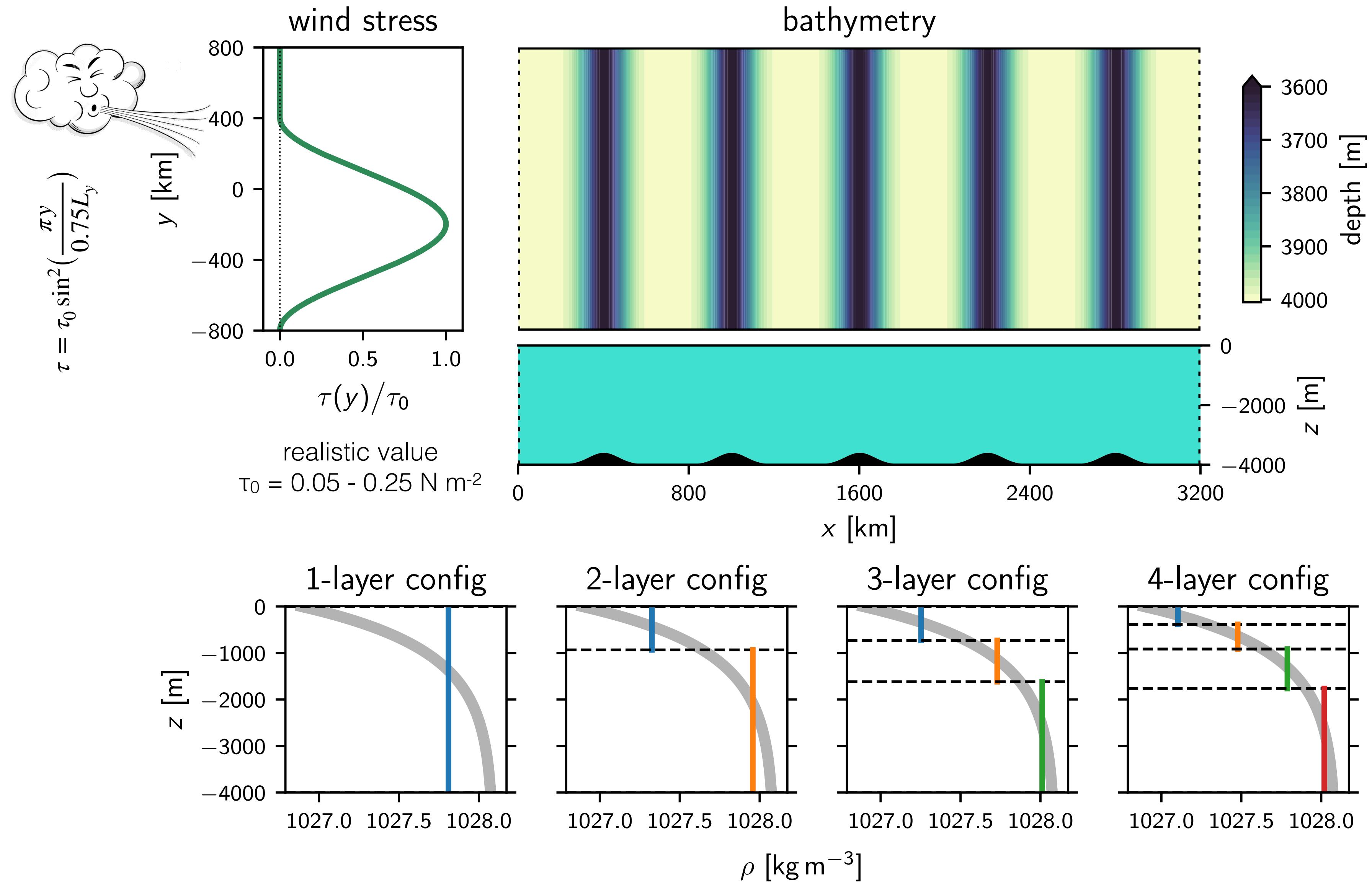
what's the plan

Assess the relative role of
barotropic versus **baroclinic** dynamics
in establishing "eddy saturated" ocean states.

Use an isopycnal layered model
with varying number of fluid layers.

model setup

GFDL's MOM6
primitive equations
in isopycnal coordinates
Boussinesq approximation



β -plane $f = f_0 + \beta y$
1st deformation radius $\approx 19 \text{ km}$
zonally re-entrant
free surface
free-slip walls
quadratic bottom drag
grid spacing 4 km

bathymetry:
Gaussian ridges
400 m tall, half-width 165 km

exponential density profile

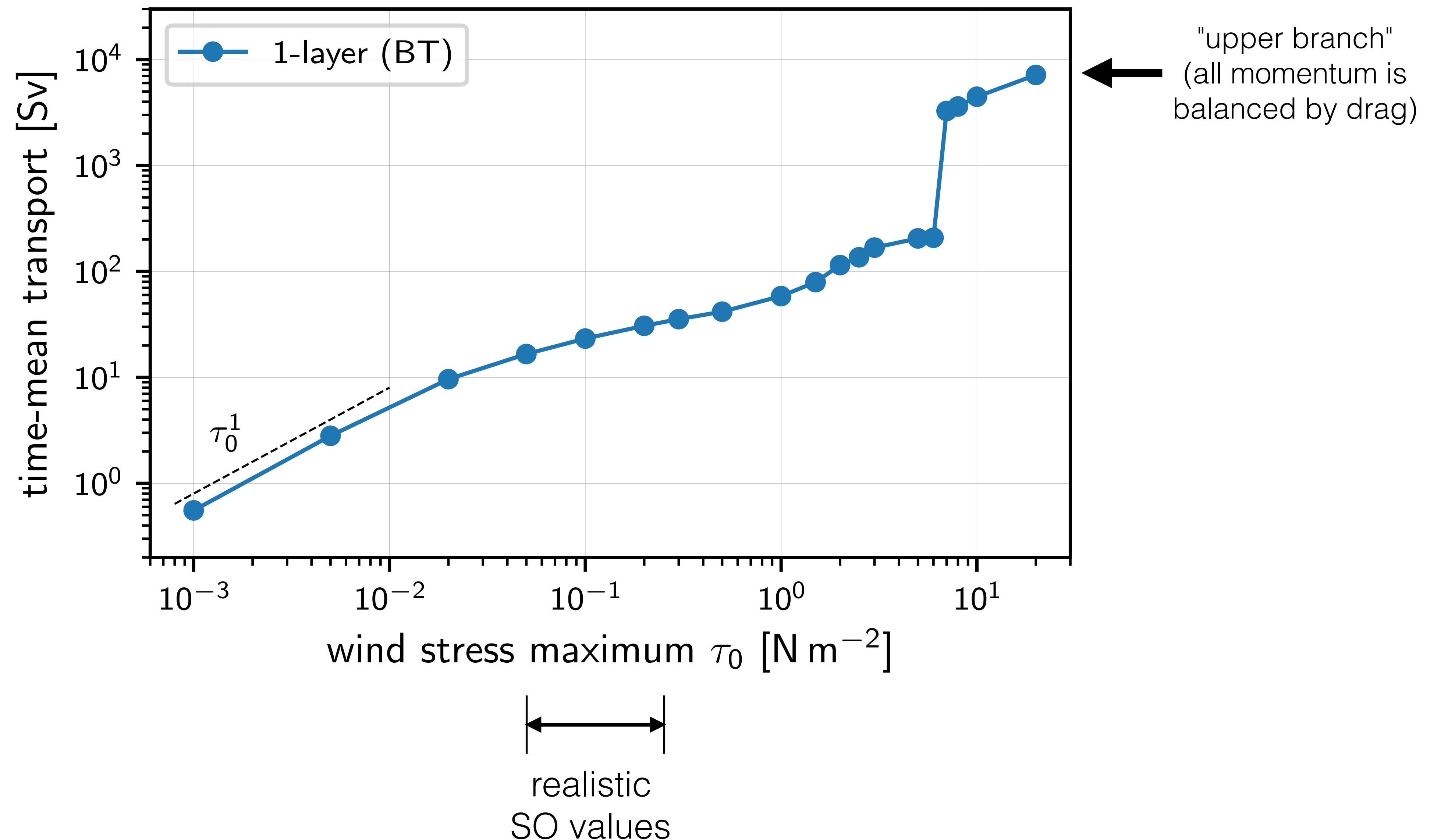
$$\rho = \rho_0 + \Delta\rho (1 - e^{z/d})$$

$$\Delta\rho = 1.2 \text{ kg m}^{-3}, d = 1 \text{ km}$$

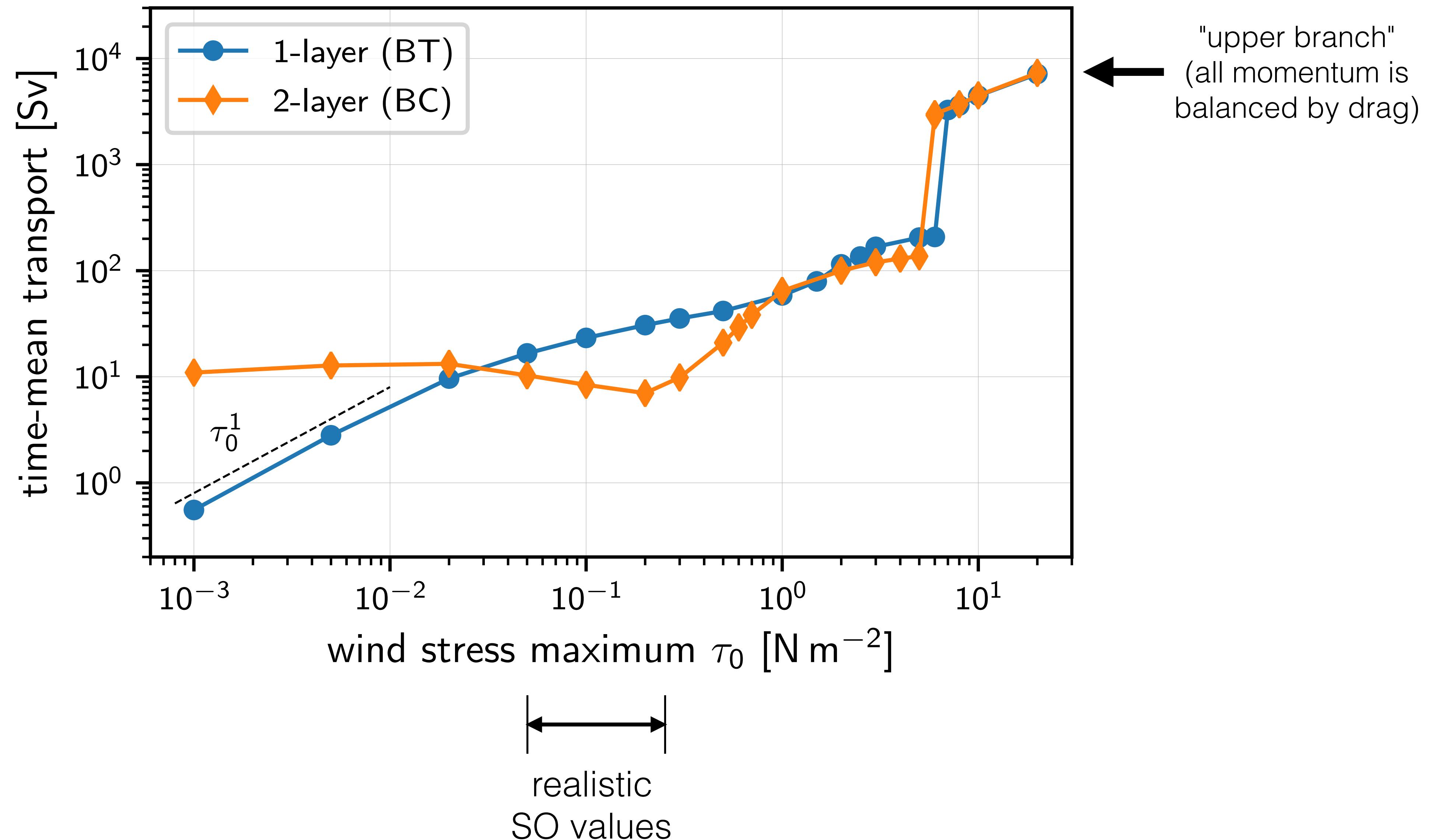
layered approximations

vary the wind stress amplitude τ_0
and see how the time-mean zonal transport changes

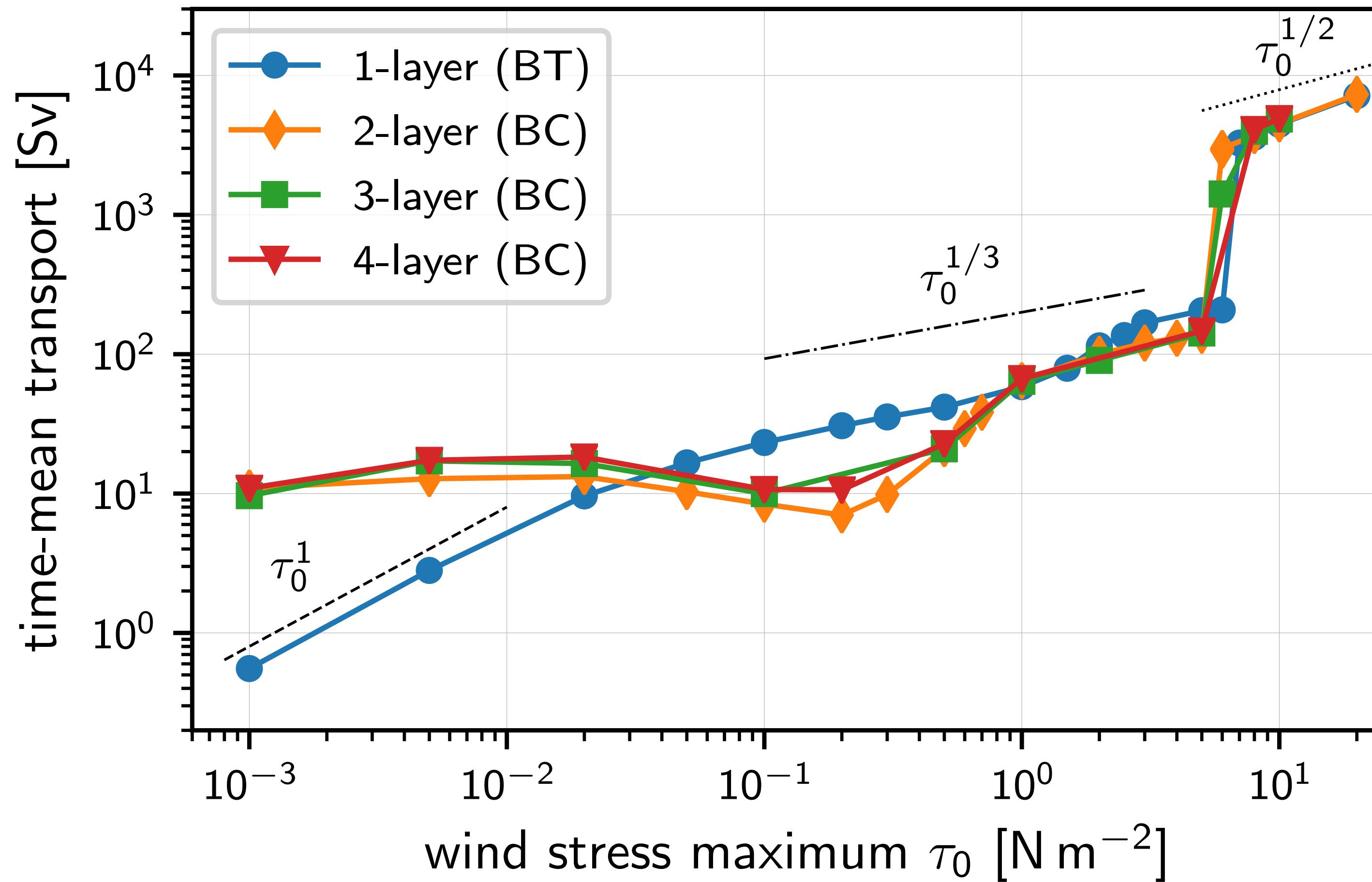
mean zonal transport Vs wind stress



mean zonal transport Vs wind stress

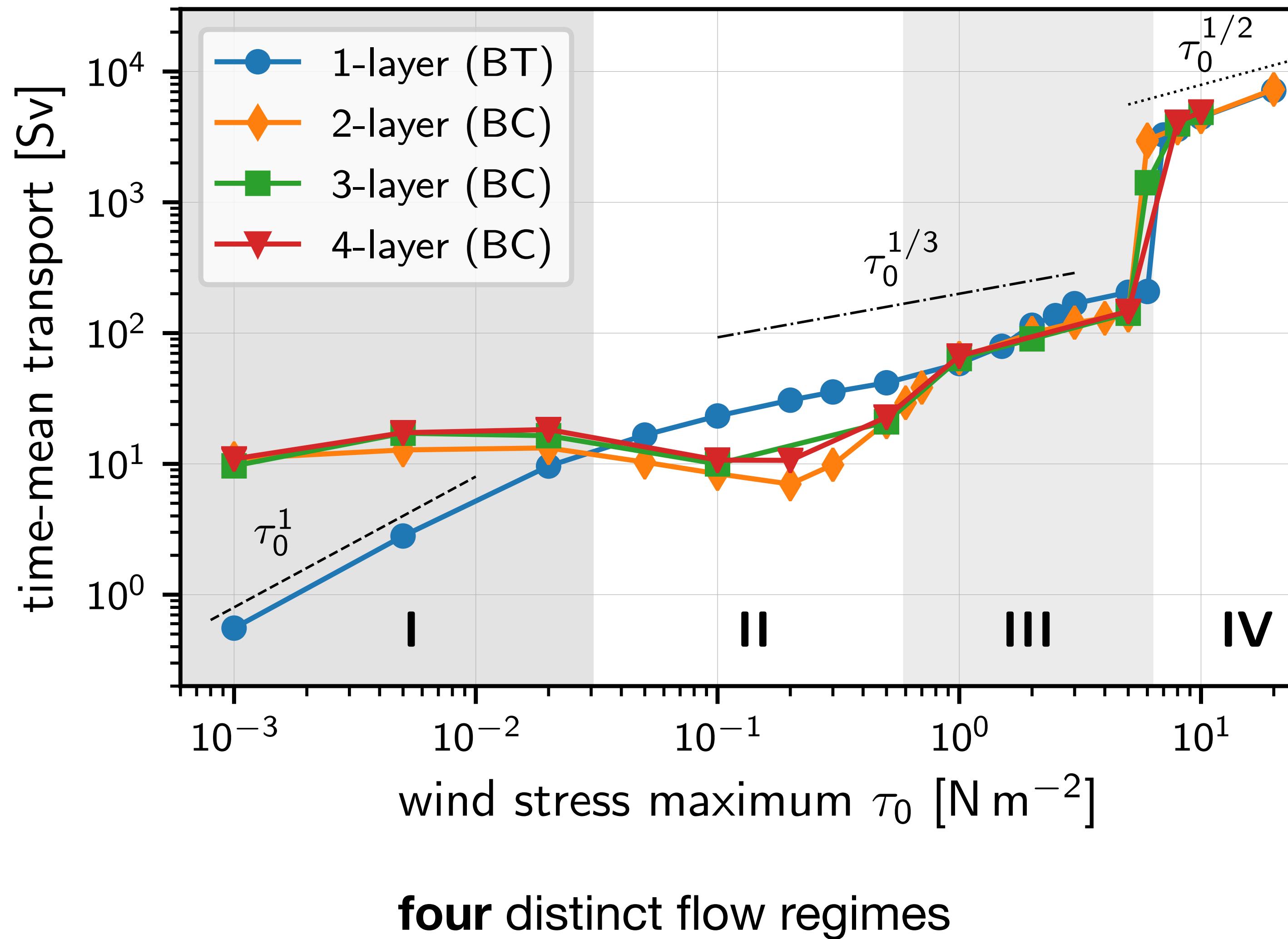


mean zonal transport Vs wind stress

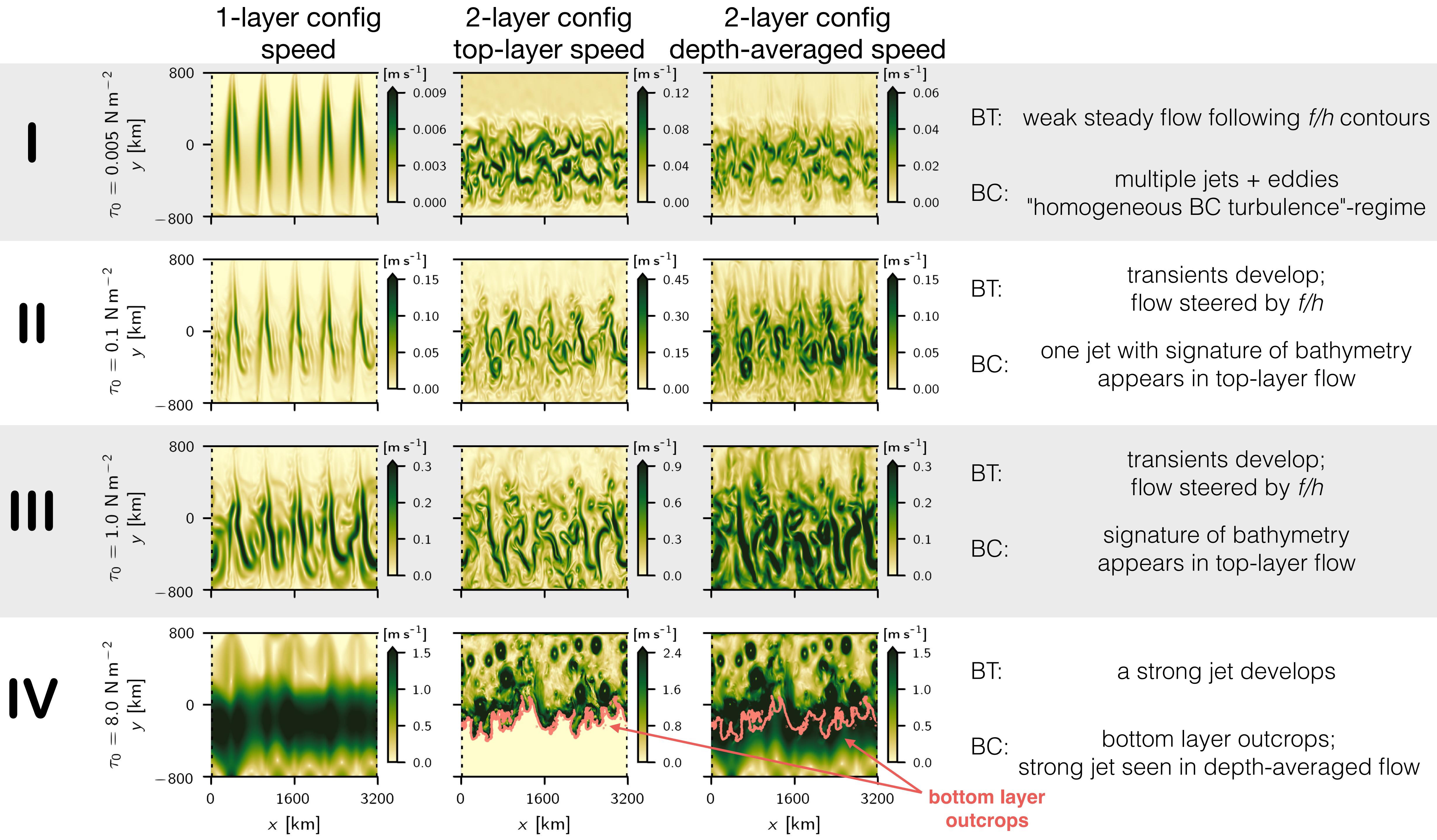


>3-layer configurations are the same as 2-layers
(as far as the mean zonal transport is concerned)

mean zonal transport Vs wind stress



how does the flow look like in the four flow regimes?



depth-integrated zonal momentum balance

$\langle \rangle$: layer average
 $\overline{}$: time average

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

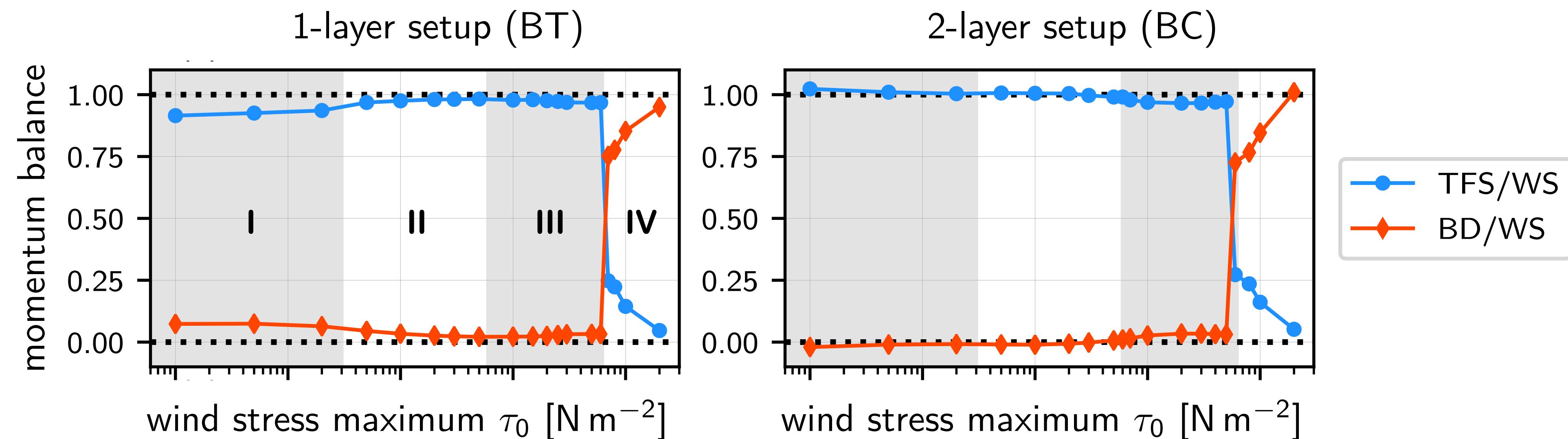
$$\langle \overline{p_{\text{bot}} \partial_x h_{\text{bot}}} \rangle = \langle \overline{p_{\text{bot}}} \partial_x h_{\text{bot}} \rangle$$

only standing flow
contributes to TFS

wind
stress
(WS)

topographic
form stress
(TFS)

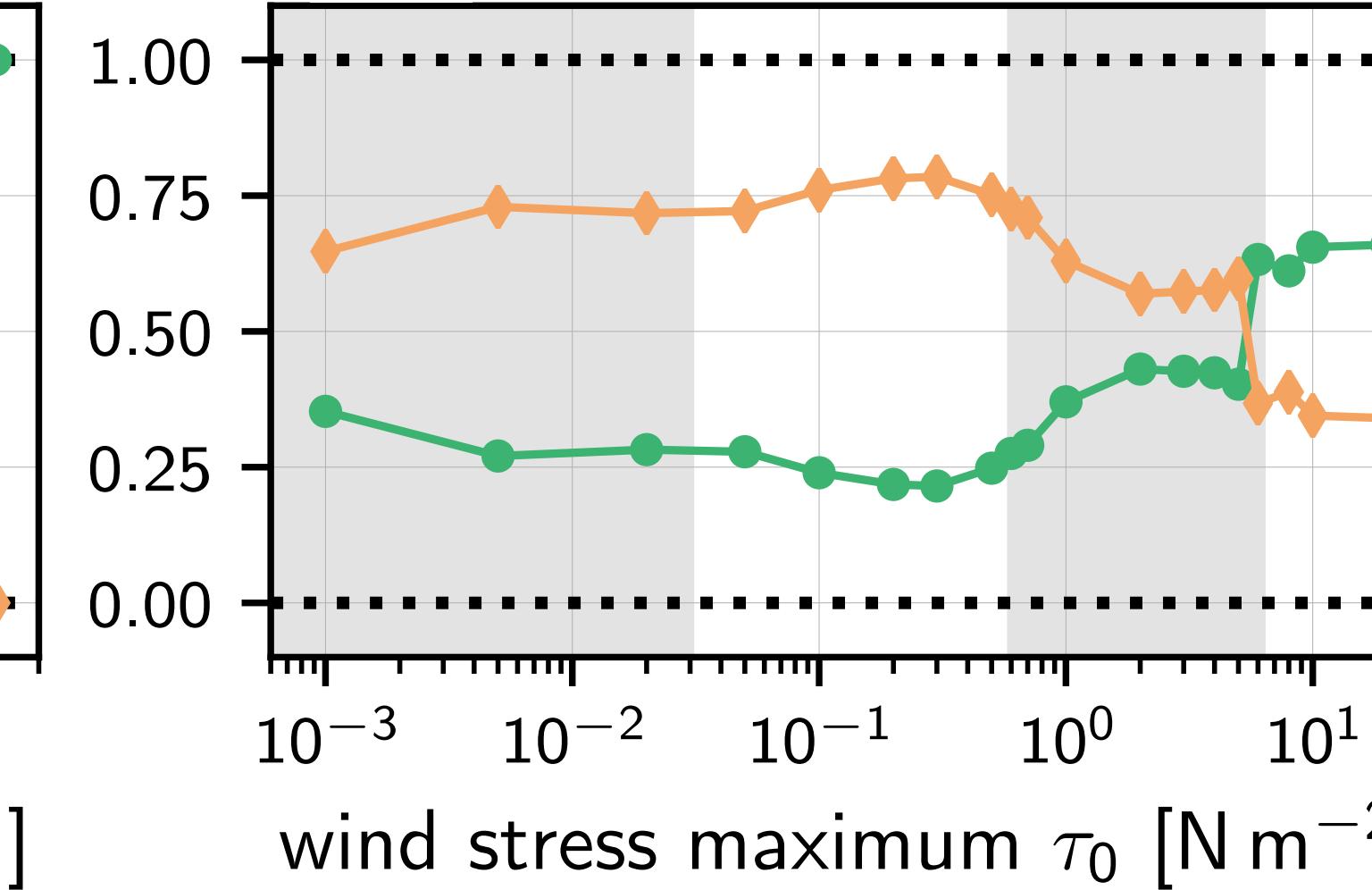
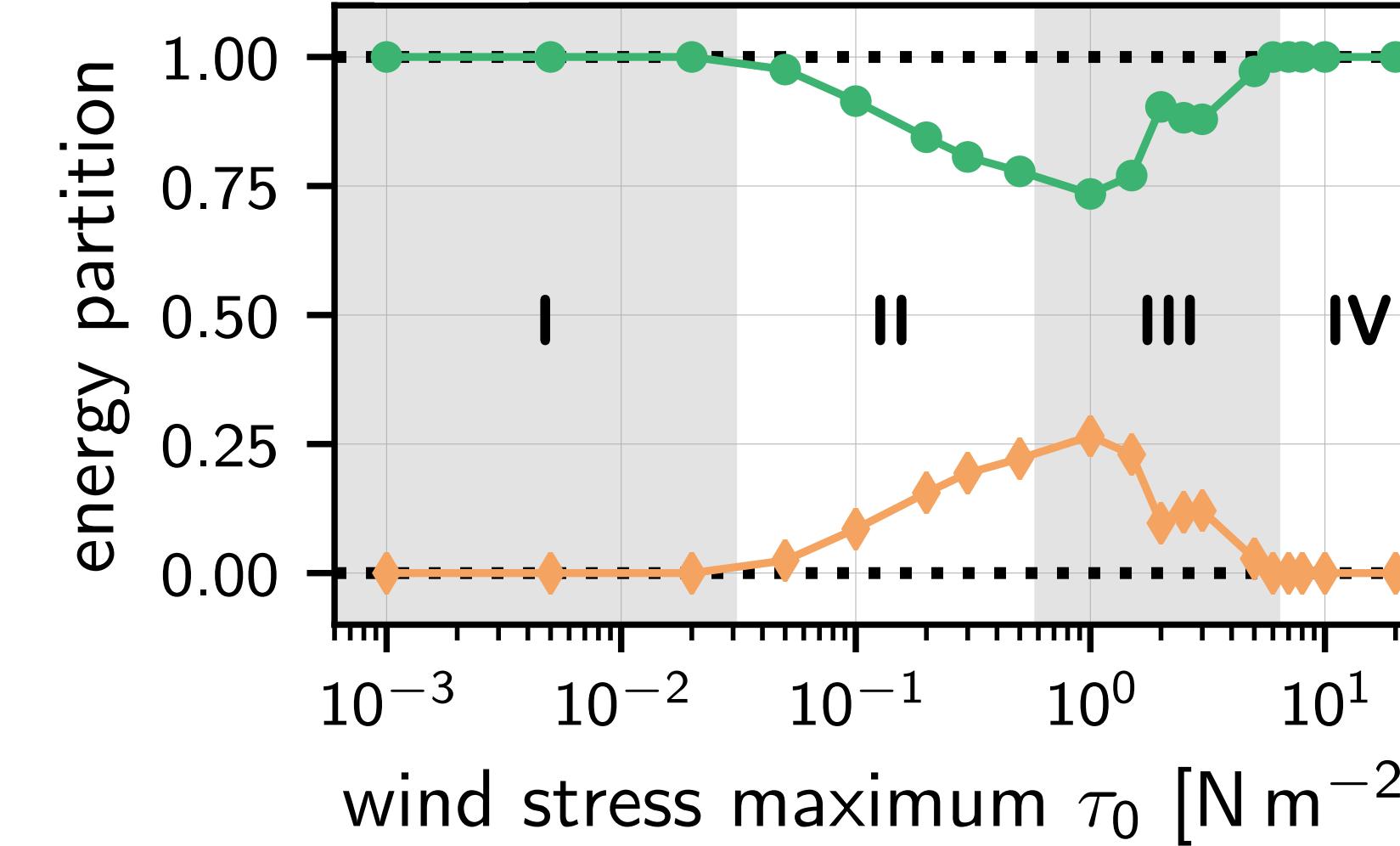
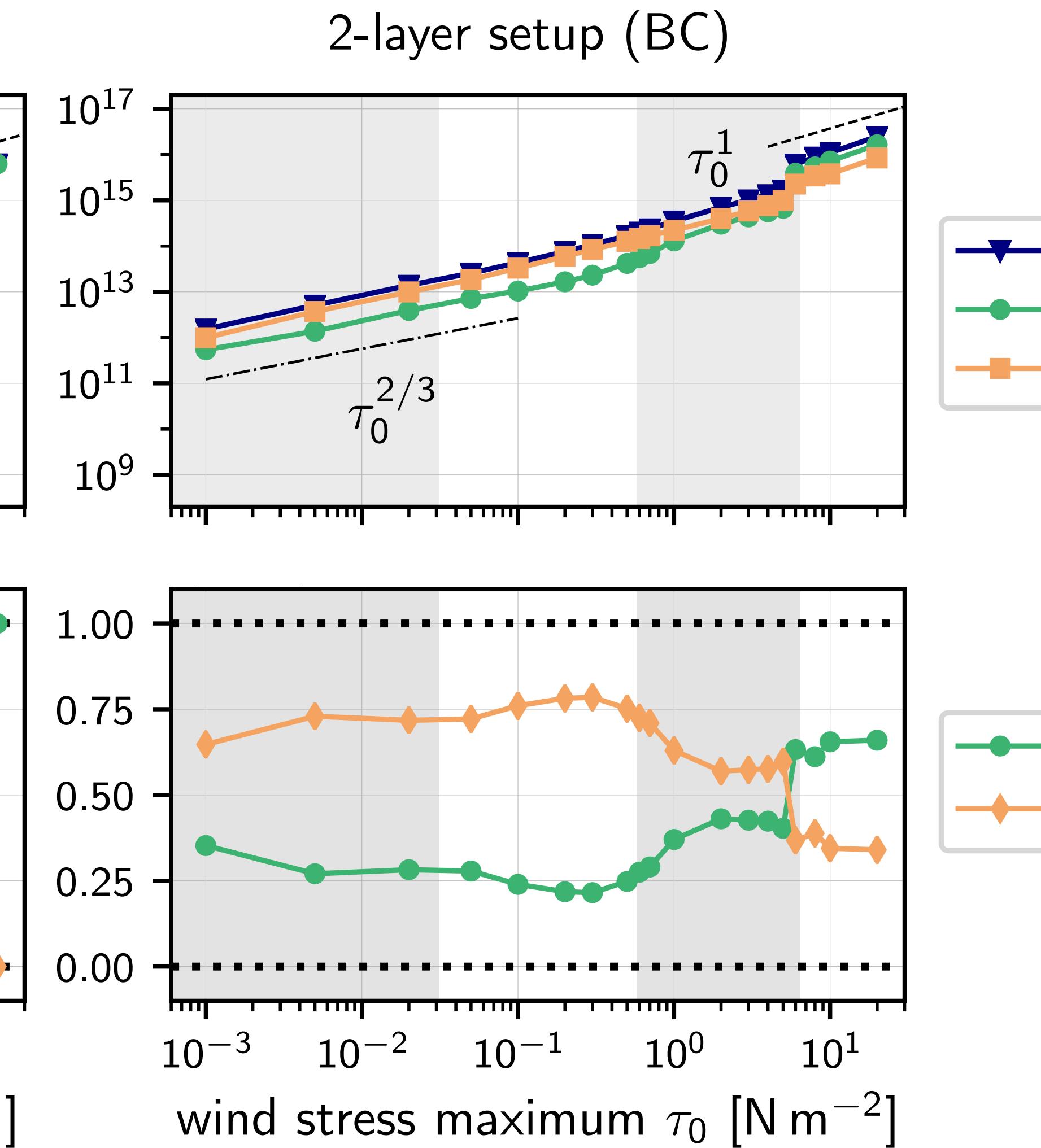
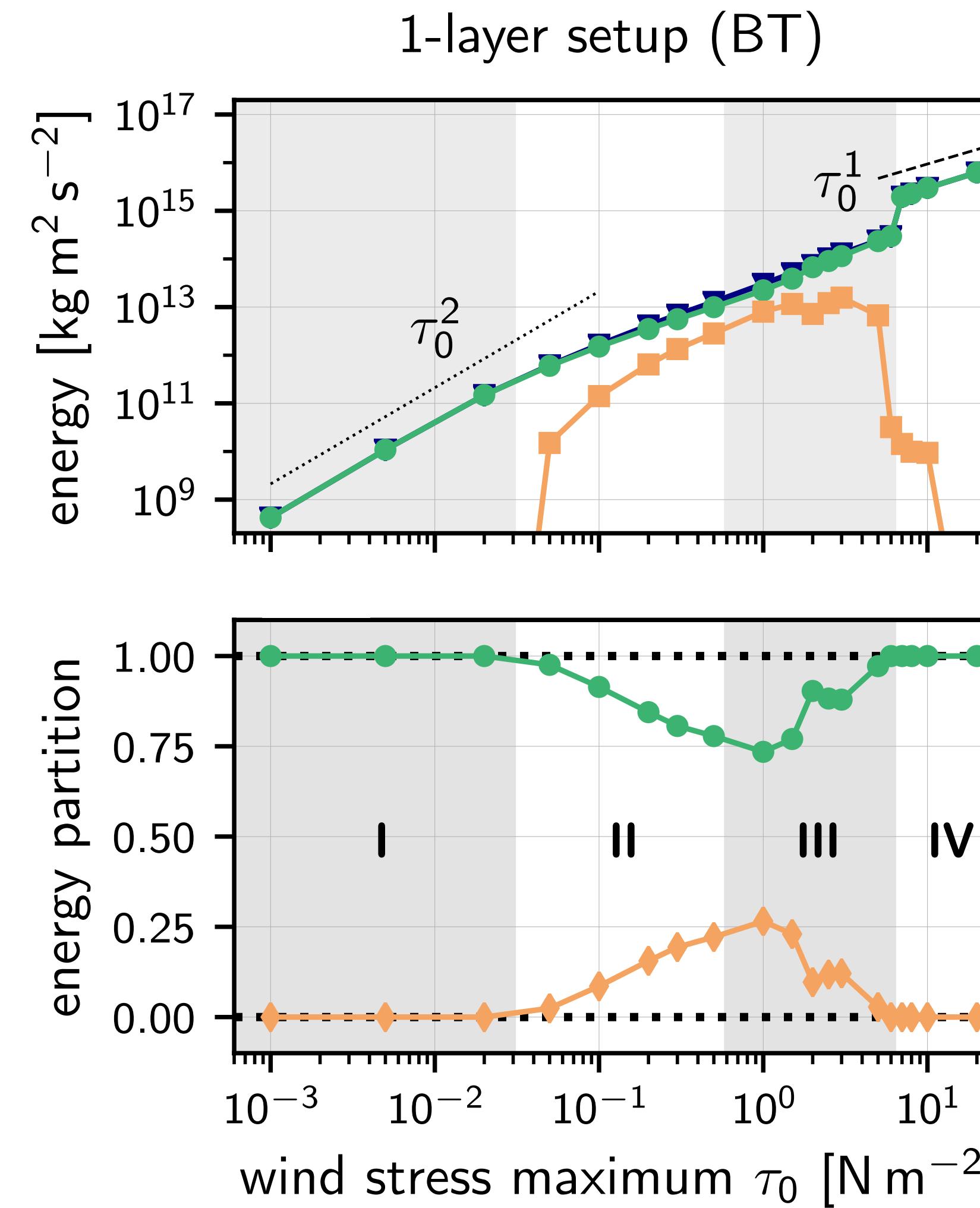
bottom drag
(BD)



Almost all momentum is balanced by topographic form stress
(except when flow transitions to "upper branch").

standing–transient kinetic energy decomposition

BT config
has transients
only in **II & III**



standing flow
dominates
in BT config;
transient flow
dominates in BC

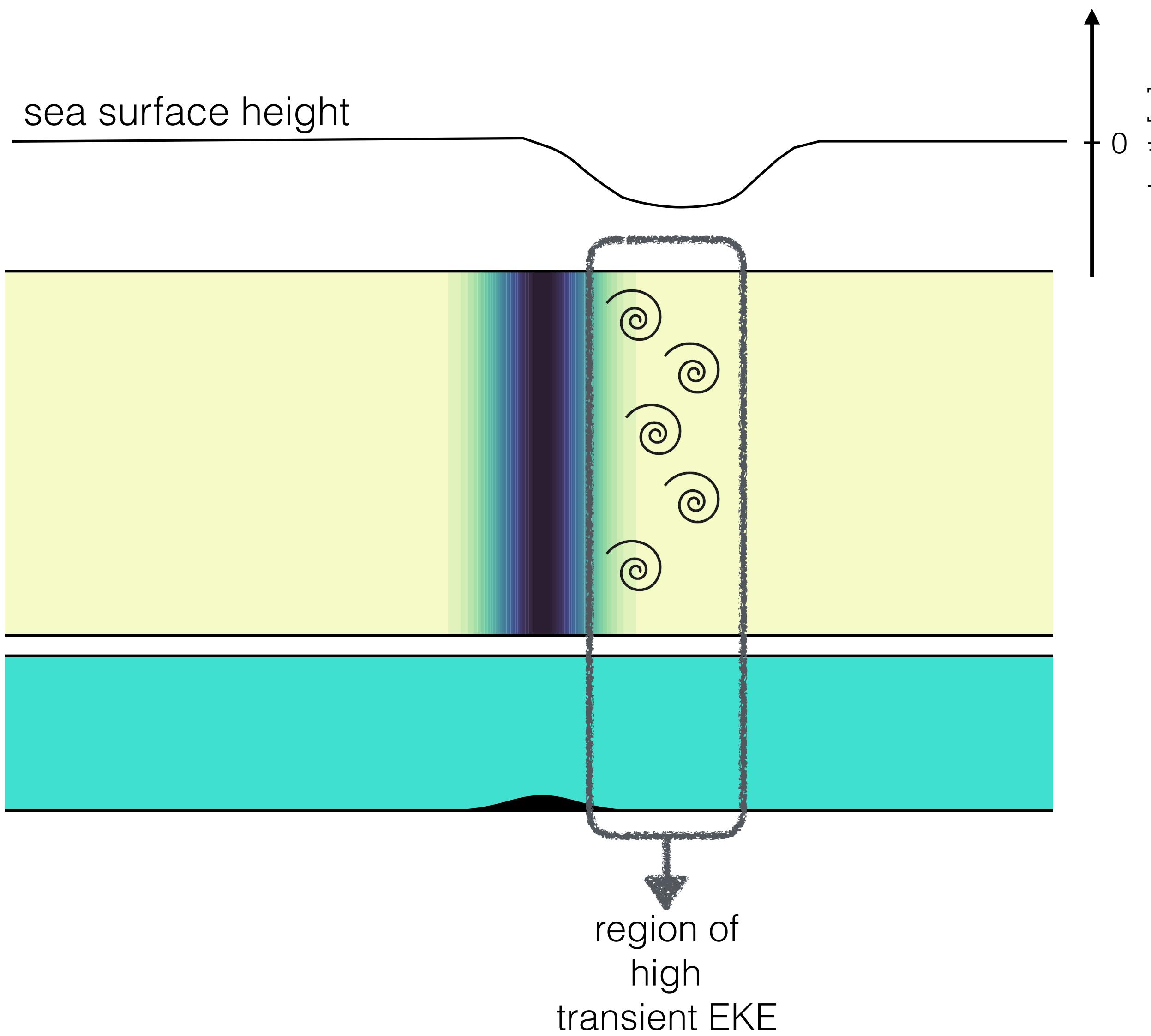
Despite the great differences in flow fields,
both **BT** and **BC** configs show same mean zonal transport for regimes **III & IV**.

$$\langle \overline{p_{\text{bot}} \partial_x h_{\text{bot}}} \rangle = \langle \overline{p_{\text{bot}}} \partial_x h_{\text{bot}} \rangle$$

only standing flow contributes to
topographic form stress

how transients affect
topographic form stress?

how transients lead to time-mean topographic form stress?



[Same process as described by Youngs et al. 2017]

take home messages

when transient eddies exist (both in **barotropic** or **baroclinic** configs)
the mean zonal transport becomes eddy saturated
[transport is much less sensitive to wind stress increase]

proposal:

eddy saturation occurs due to
transient eddies shaping the standing flow
to produce topographic form stress that balances the wind stress
(*regardless* of the process from which transient eddies originate)

our results show that the (oftentimes ignored) barotropic flow-component
plays an important role in setting up the ACC transport

[in agreement with recent obs. evidence, e.g., Thompson & Naveira Garabato 2014,
Peña-Molino et al. 2014, Donohue et al. 2016 (cDrake exp)]

thank you