THE UNIVERSITY OF CHICAGO

The impact of topography and eddy parameterization on the simulated Southern Ocean circulation response to changes in surface wind stress

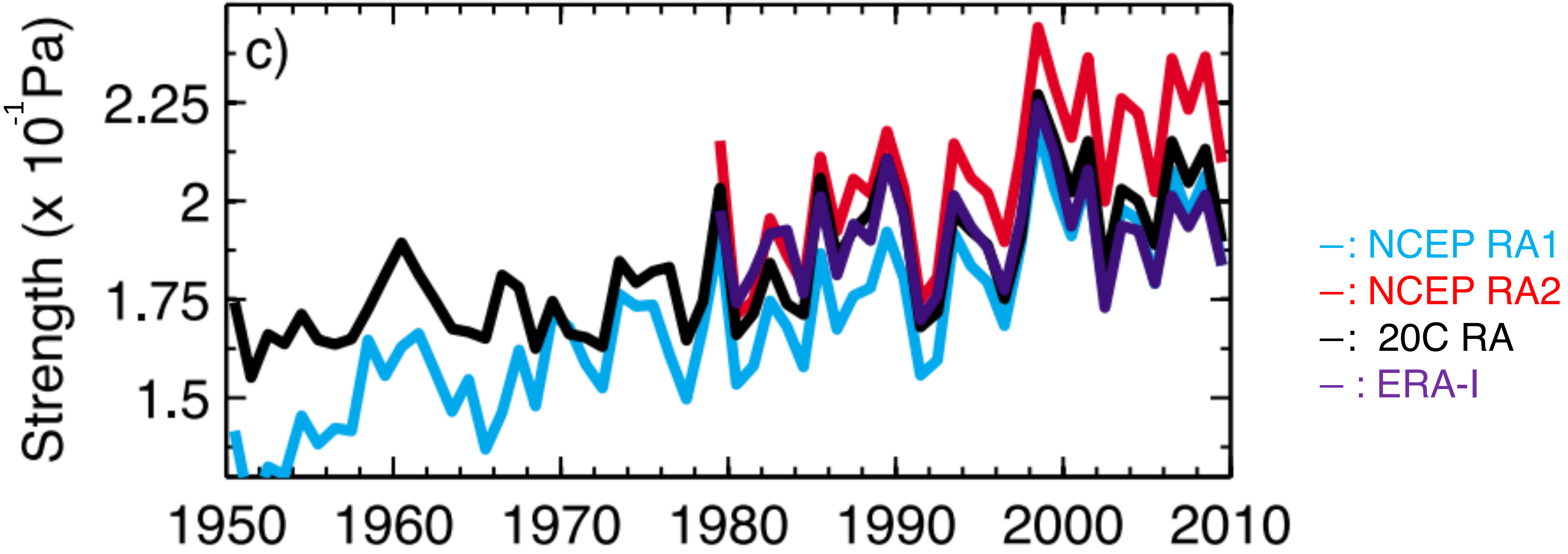
Hailu Kong, Malte Jansen

The University of Chicago

CESM Ocean Working Group Meeting
February 2021

Kong & Jansen, 2020, JPO

Surface wind stress intensifies over the Southern Ocean



Swart & Fyfe, 2012

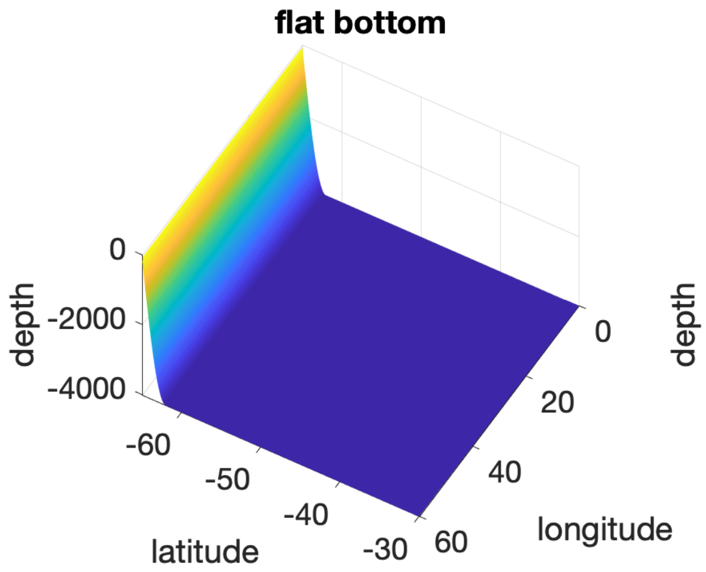
Questions to address

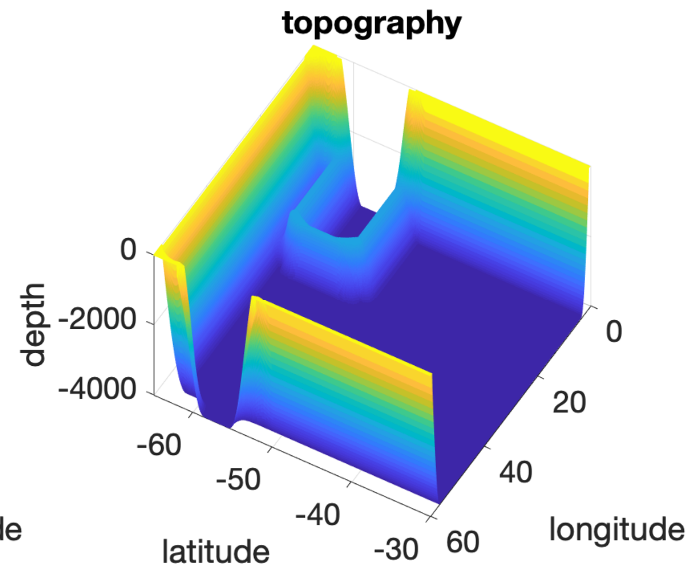
- How does Southern Ocean circulation respond to wind stress changes?
  - Antarctic Circumpolar Current (ACC)
  - Meridional overturning circulation (MOC): upper cell

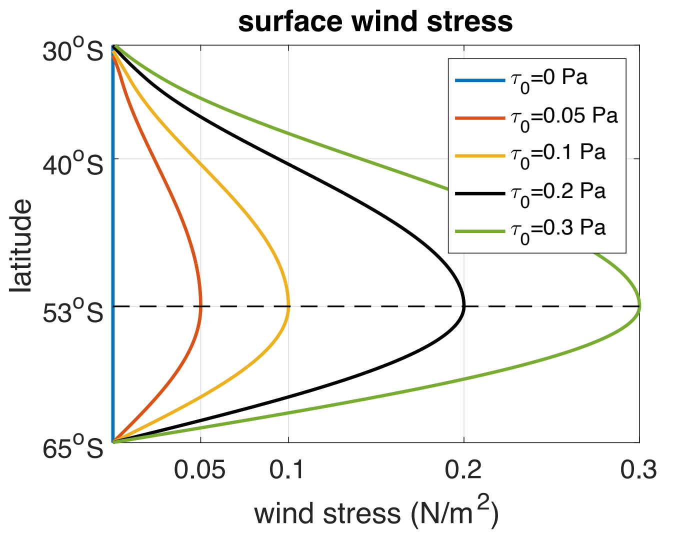
- How may topography affect this response?

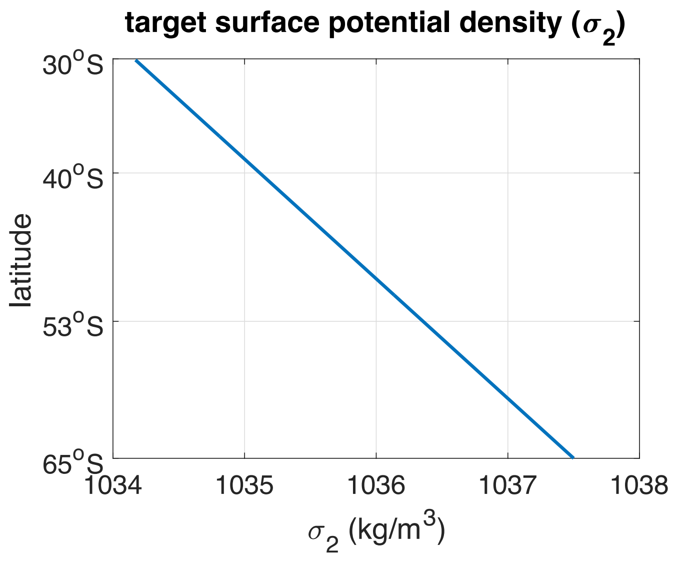
- Can coarse resolution models (with parameterized mesoscale eddies) capture the response?

An idealized MOM6 configuration for the Southern Ocean



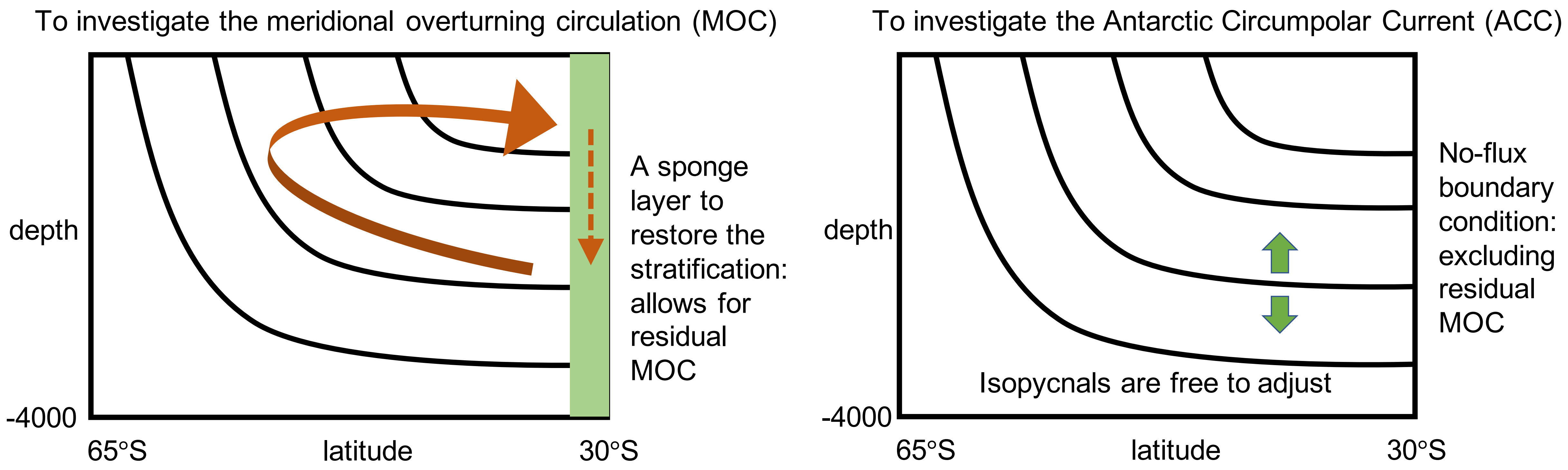






- MOM6 in isopycnal coordinate: 30 layers
- 0.1°: resolving mesoscale eddies
- 1°: parameterizing mesoscale eddies

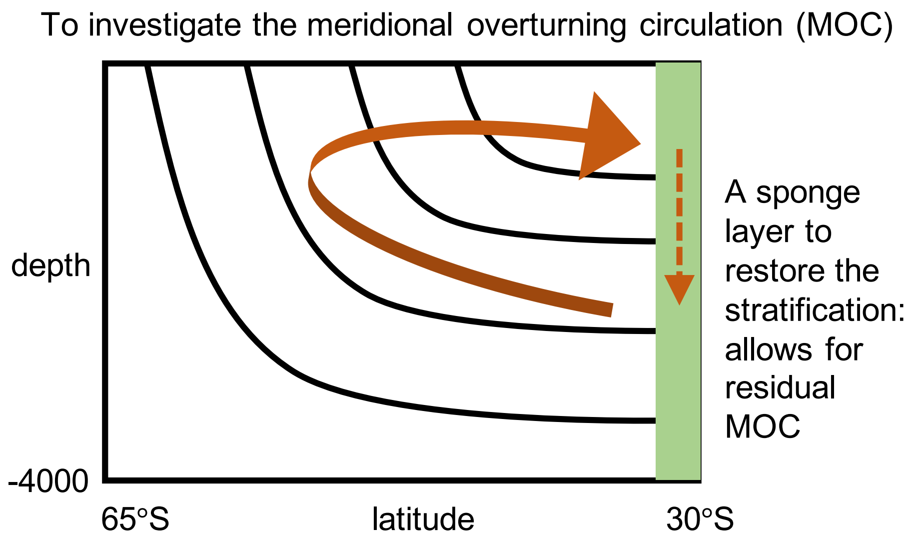
Northern boundary condition



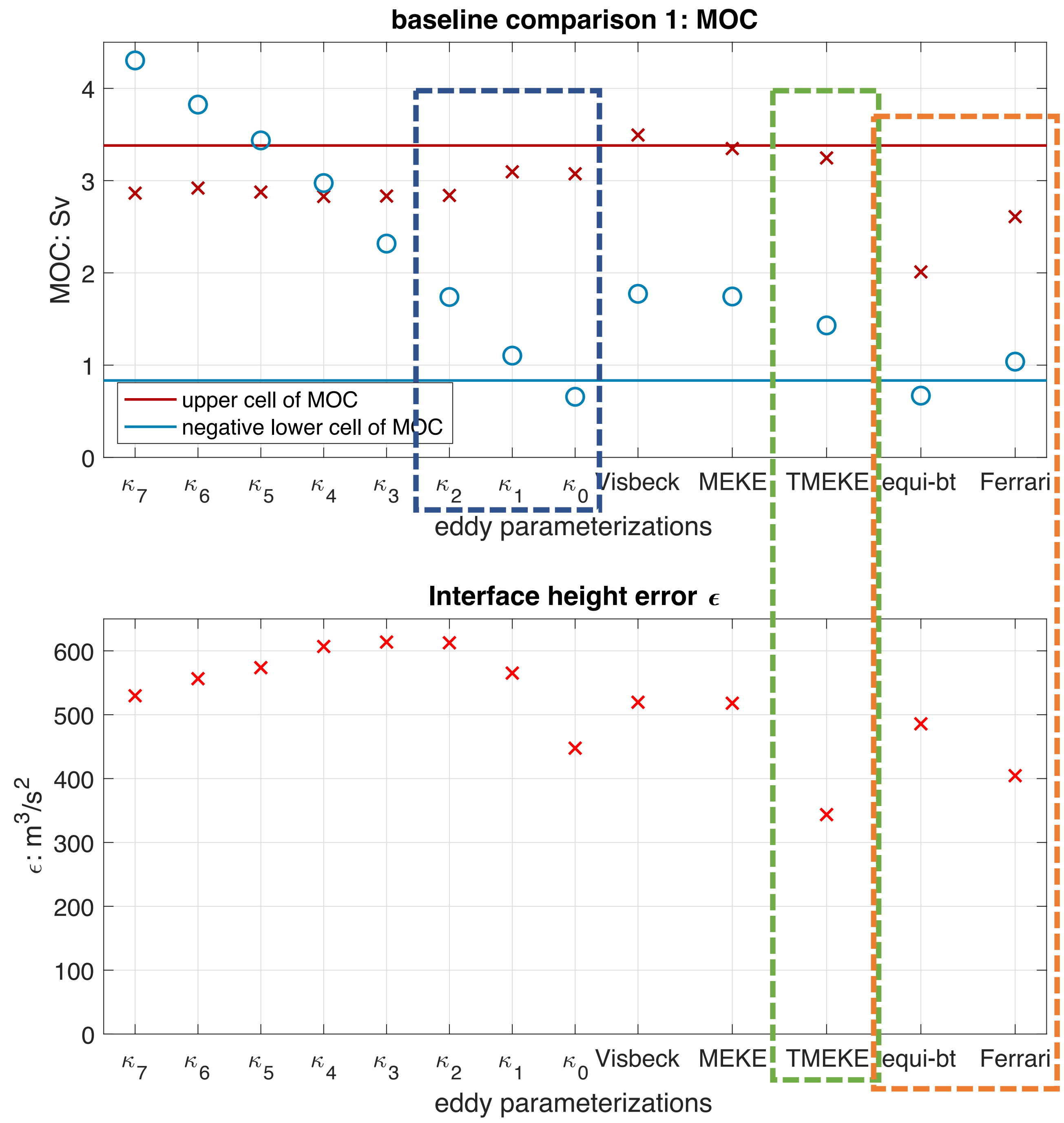
Mesoscale eddy parameterizations

- Constant κ_{GM}: $\kappa_7 = 700m^2/s$, $\kappa_6 = 600m^2/s$, …, $\kappa_0 = 0m^2/s$
- Visbeck: $\kappa_{GM} = \alpha L^2 \langle SN \rangle$
  - Visbeck et al. 1997
- MEKE: meso-scale eddy kinetic energy: $\kappa_{GM} = \sqrt{E} \cdot L_R$
  - Eden & Greatbatch 2008; Jansen et al. 2015 $\partial_t E = \dot{E}_{GM} - \dot{E}_{frc} + \nabla \cdot T$
- TMEKE: topographic MEKE – using topographic β in Rhines Scale L_R:
  - Jansen et al. 2019 $\beta^* = |\beta \hat{\mathbf{y}} + f \nabla H / H|$
- TMEKE + vertically varying κ_{GM}:
  - equi_bt: using an equivalent barotropic structure for κ_{GM} *(MOM6: KHTH_USE_EBT_STRUCT = True)*
  - Ferrari: solving a vertical elliptical equation
    - Ferrari et al. 2010

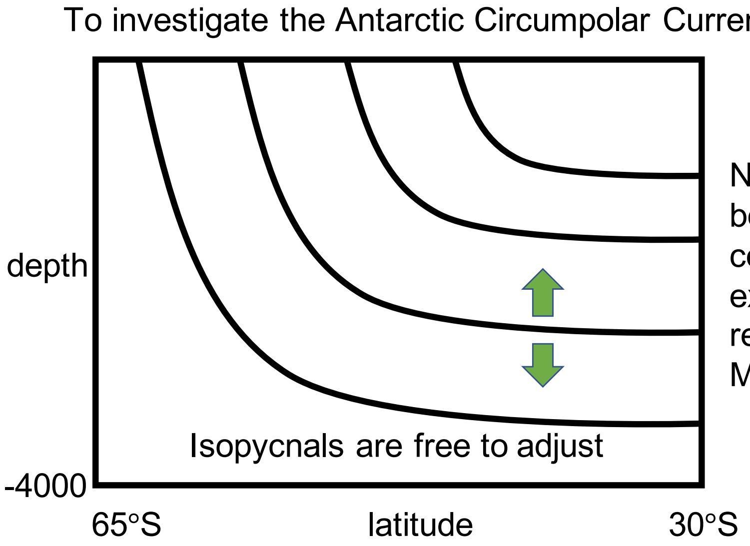
Baseline comparison 1: reference wind stress + topography + sponge

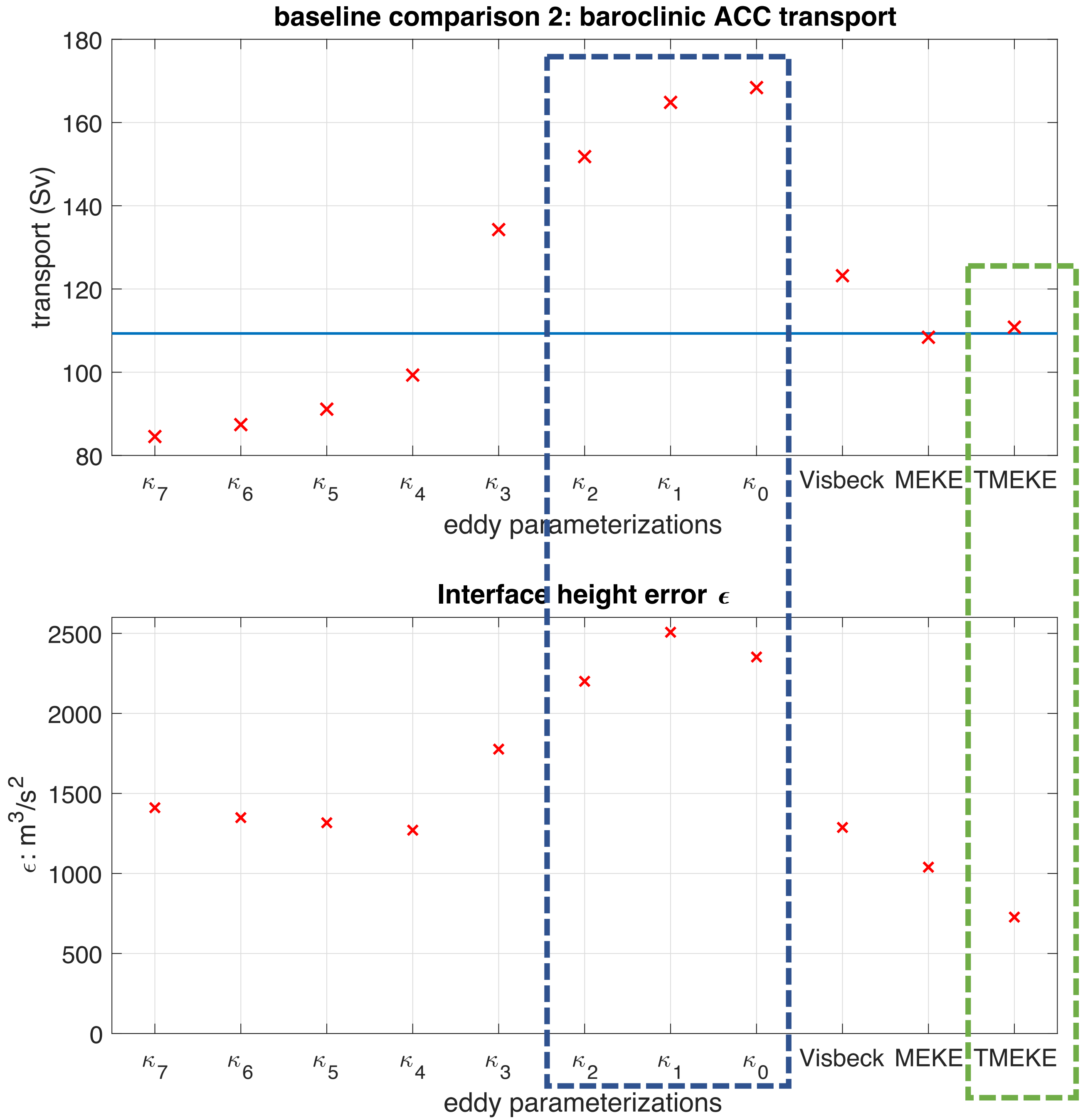


1. Small κ_{GM} can reproduce the MOC
2. Vertically varied κ_{GM} doesn't help
3. TMEKE is the best!

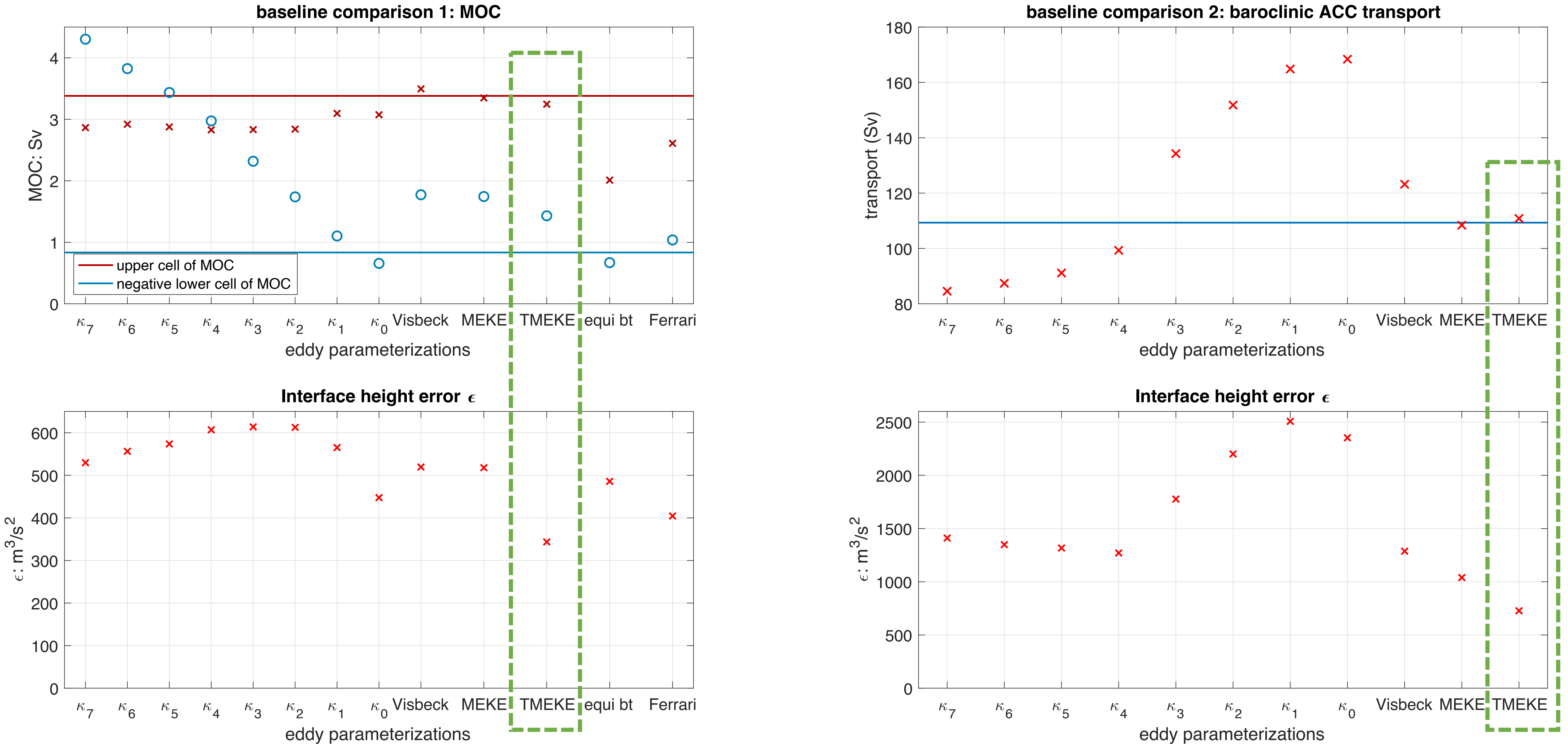


Baseline comparison 2: reference wind stress + topography & NO sponge





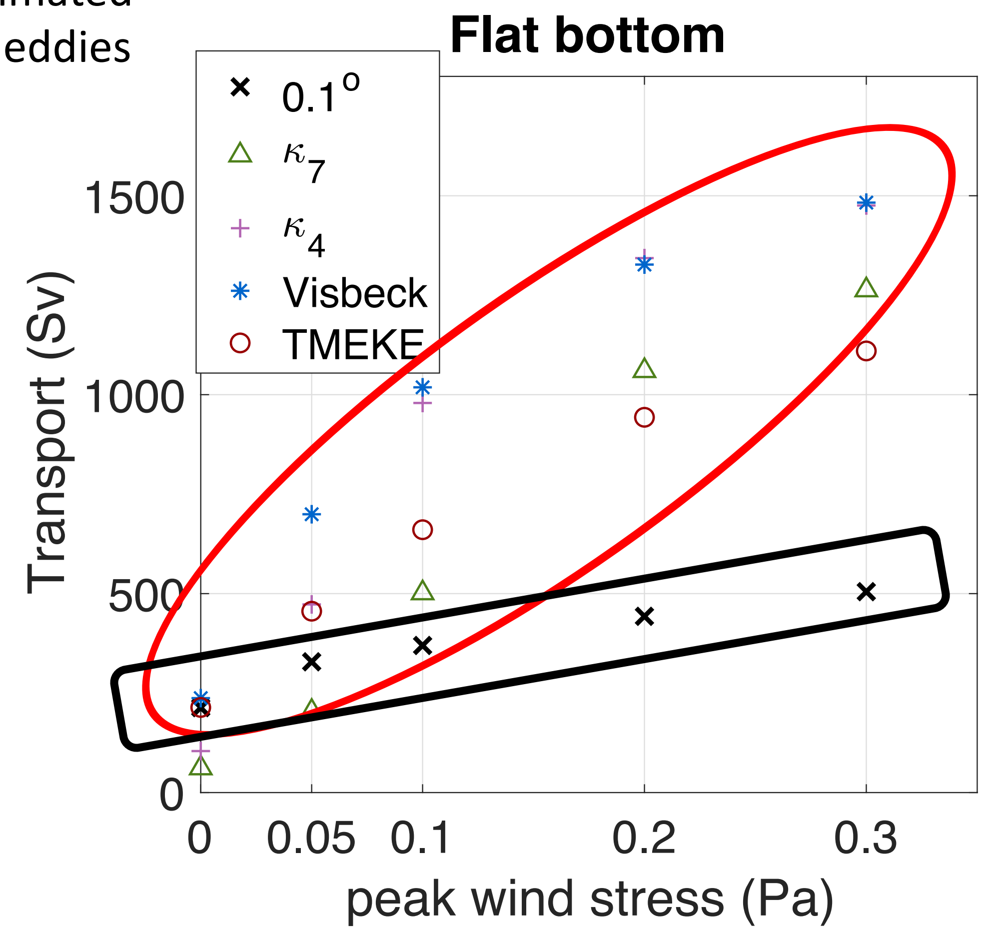
1. Small κ_{GM} can NOT capture the ACC
2. TMEKE is the best!



- constant κ_{GM} cannot simultaneously capture the MOC & ACC
- TMEKE is the best!

Antarctic Circumpolar Current (ACC) response

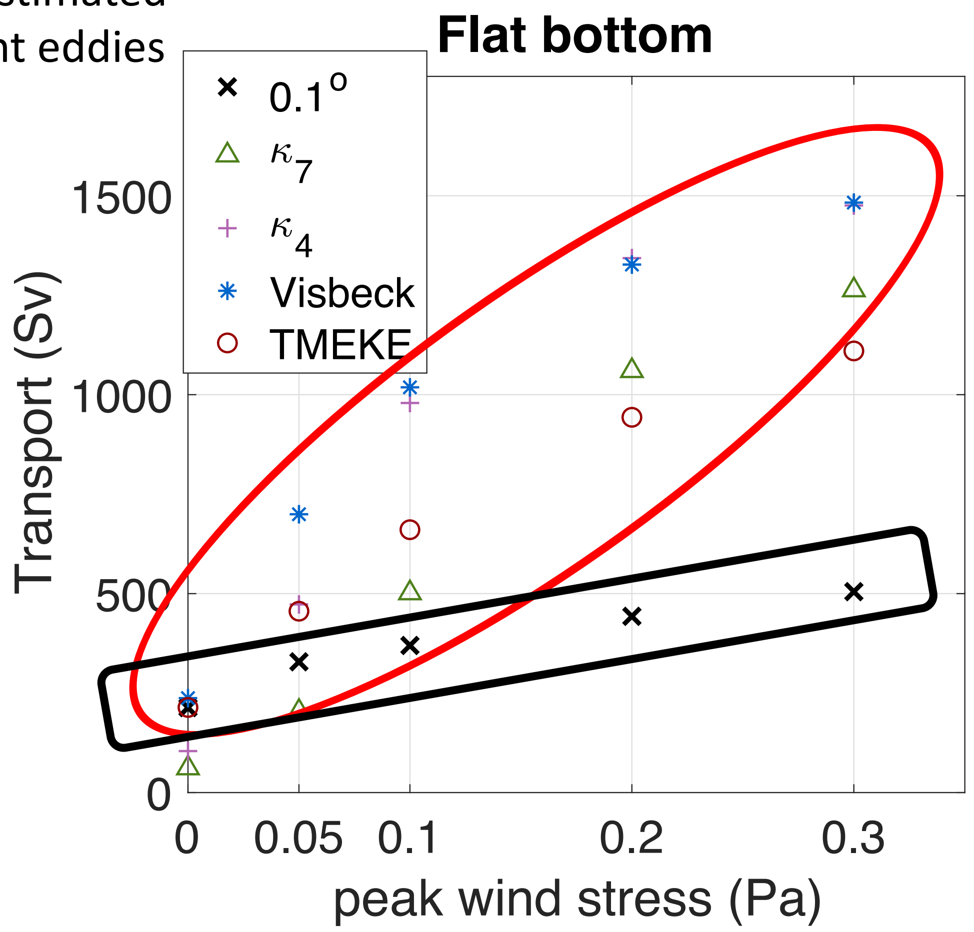
Underestimated transient eddies



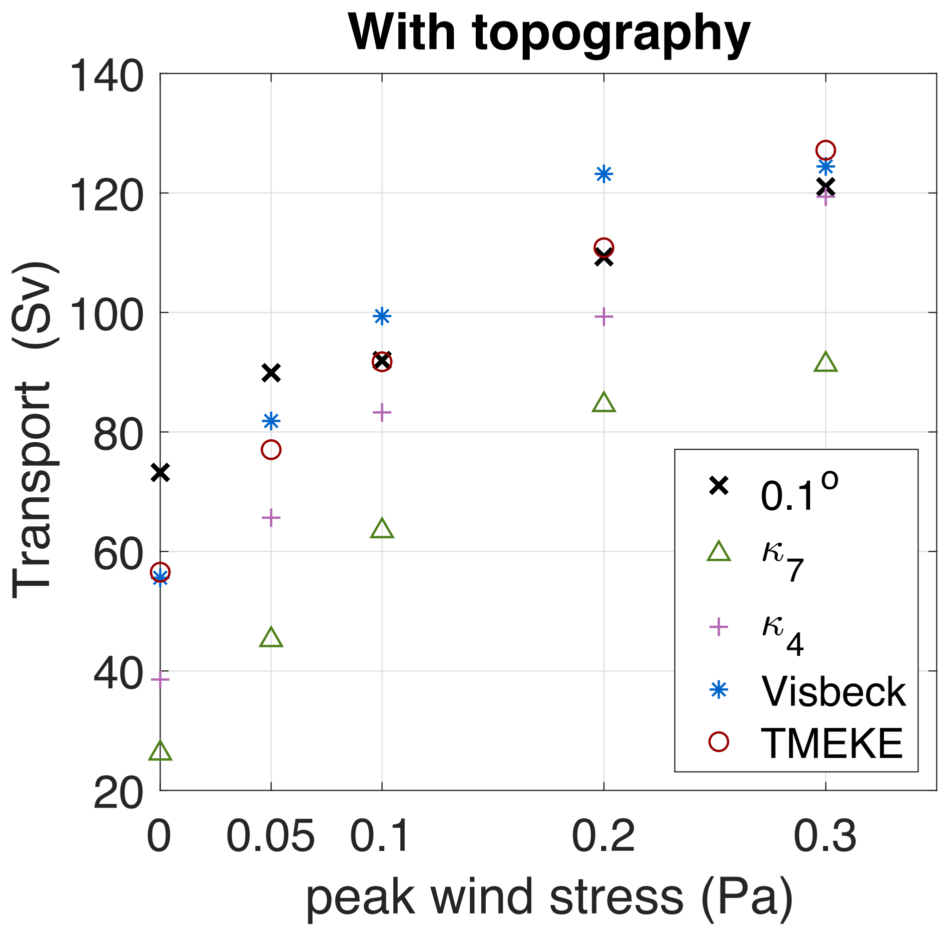
Insensitive response of the ACC transport

Antarctic Circumpolar Current (ACC) response

Underestimated transient eddies



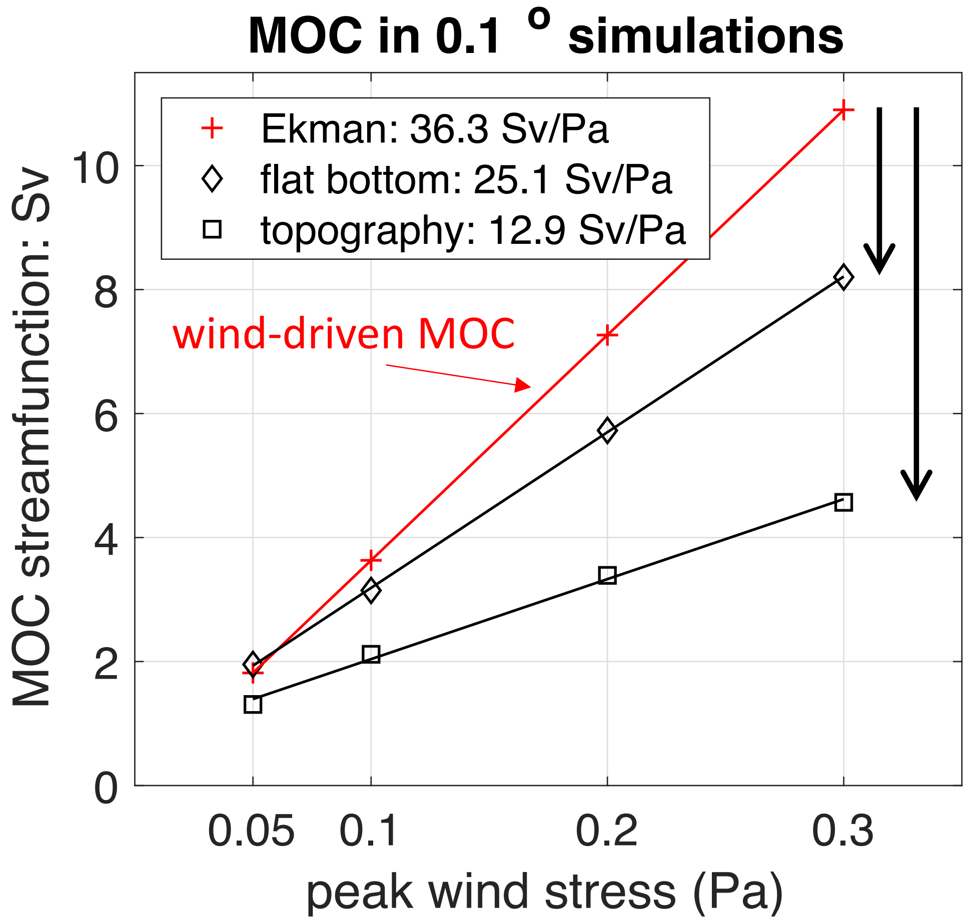
Insensitive response of the ACC transport



Correct stationary eddies, dominating over transient eddies

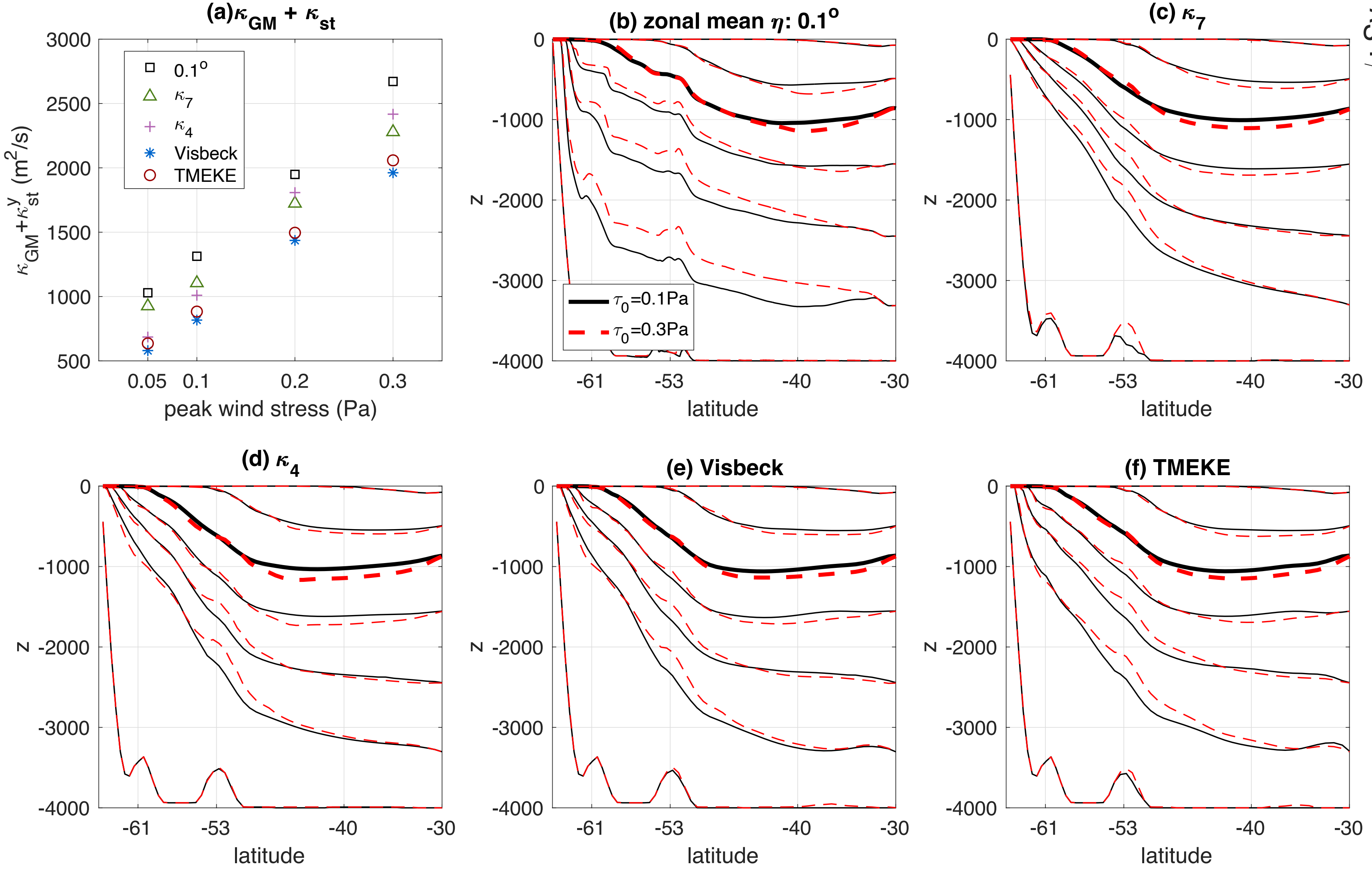
Much more insensitive response of the ACC transport

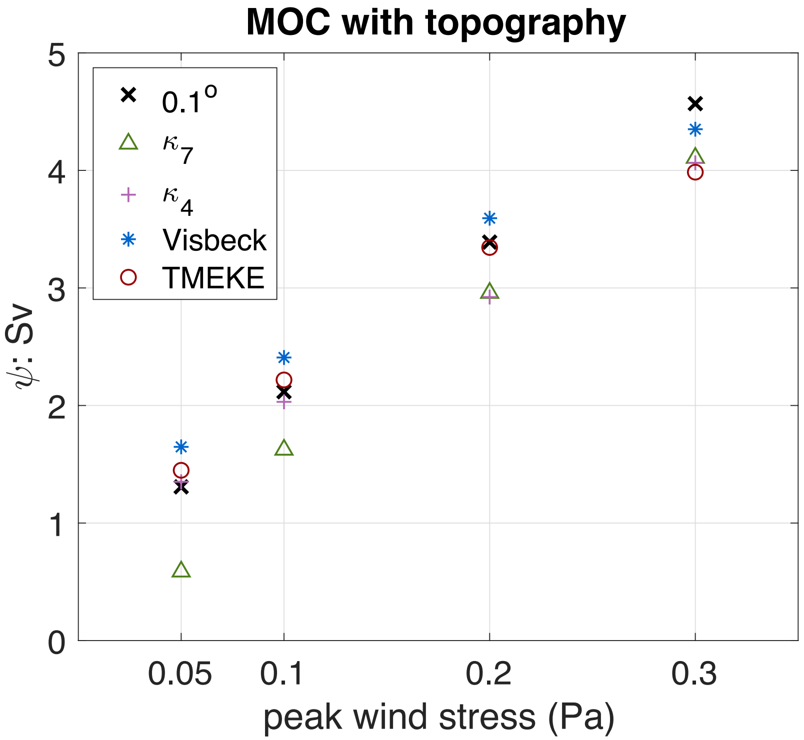
Meridional overturning circulation (MOC) response: high-resolution results



- The MOC response is suppressed due to the transient eddies in flat bottom case
- Topography significantly suppresses the MOC response
- Can coarse resolution simulations with eddy parameterizations capture the suppression?

MOC response: with topography

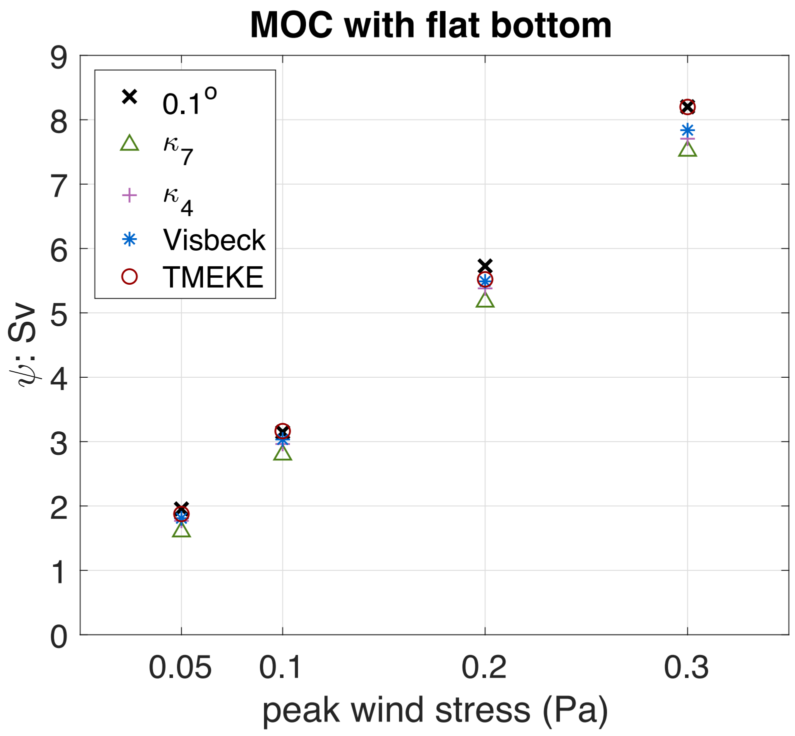


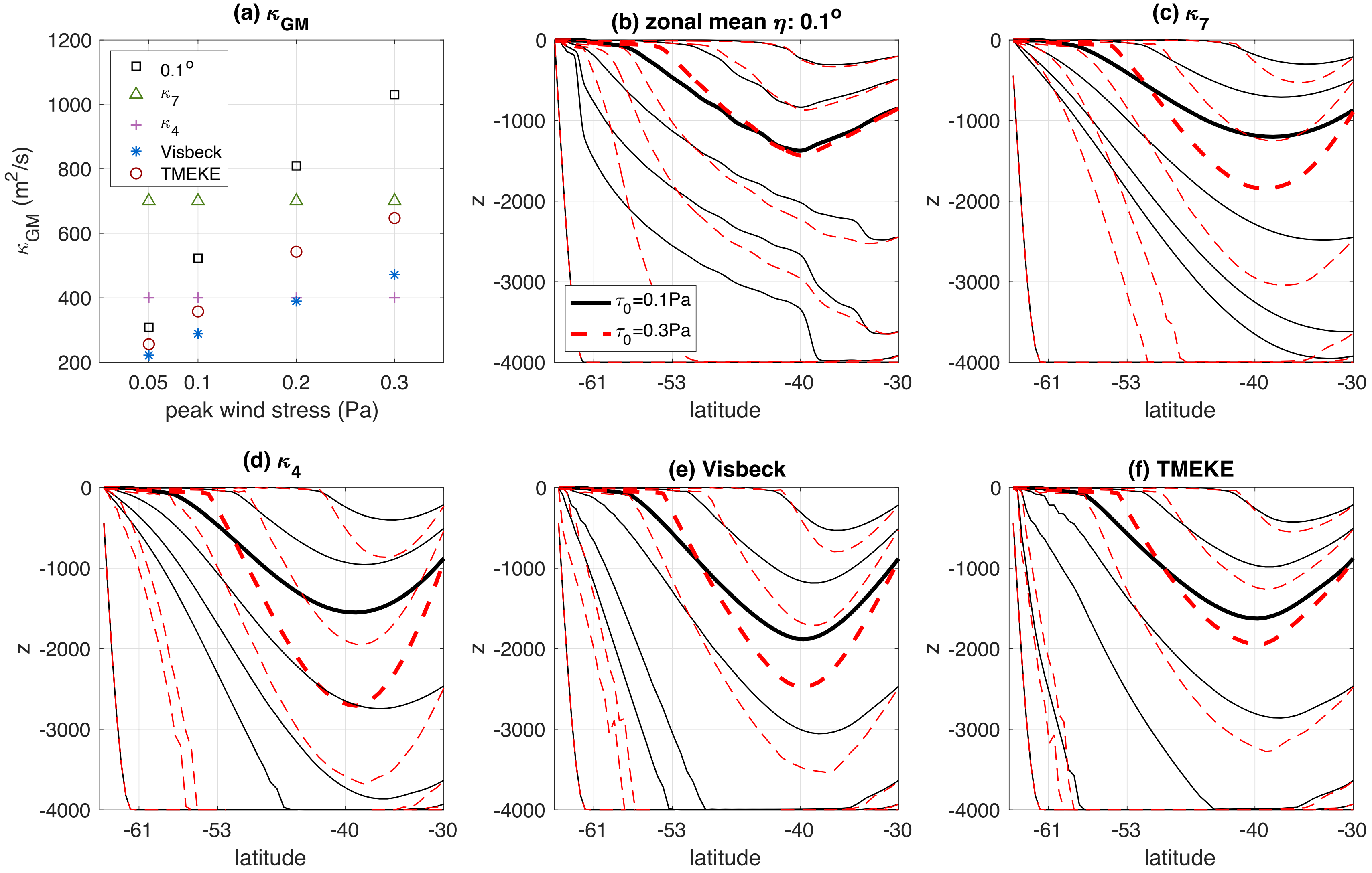


Right MOC for the right reason:

Both $\kappa_{GM} + \kappa_{st}$ and isopycnal slope right

MOC response: flat bottom





Right MOC for the wrong reason:
Both κ_{GM} and isopycnal slope are wrong but the errors compensate each other, such that $\psi = \bar{\psi}_{Ek} + \kappa_{GM} \cdot s$ remains similar to the 0.1 deg run

Conclusions

- Under reference wind stress,
  - No optimal value for a constant κ_{GM}
  - Vertical structure in κ_{GM} doesn't necessarily improve eddy parameterization
  - TMEKE performs the best!

- When wind stress changes,
  - Both the ACC & MOC remain relatively insensitive
  - Topography significantly suppresses both the ACC and MOC response; stationary eddies dominate over transient eddies
  - $1°$ simulations reasonably capture the suppression of responses of the ACC and MOC by topography, largely because stationary eddies are resolved
  - Reasonably confident in climate model simulations