The Impacts of Bottom Drag on the Sensitivity of the Southern Ocean Circulation to the Changing Wind

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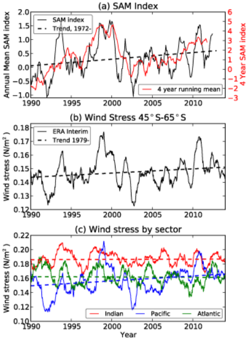
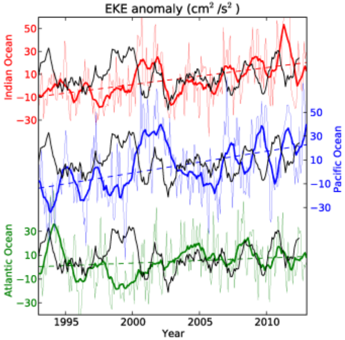
Introduction



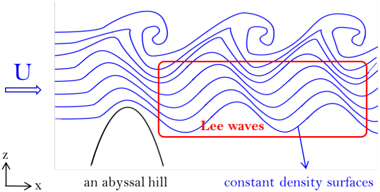


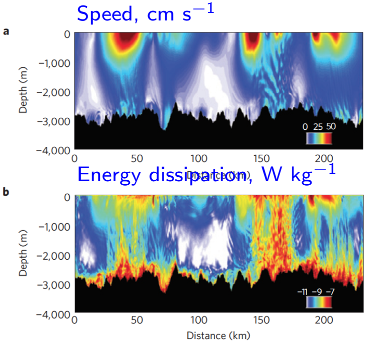
Hogg et al. (2015)

- **Westerly wind** over the Southern Ocean has been strengthening and shifting poleward.
- Stronger wind is found to generate a stronger **eddy** field.

Introduction

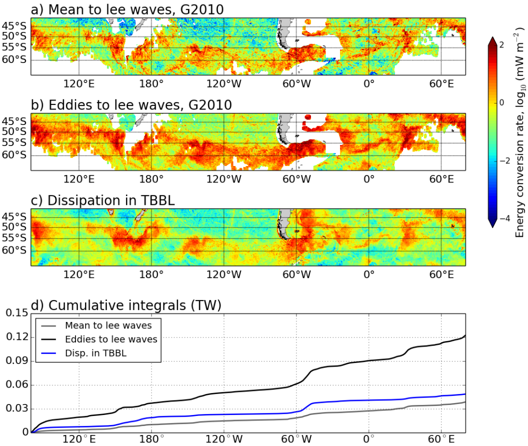
- The response of the Southern Ocean circulation is regulated by the **eddy field**, the strength of which is affected by **its energy loss** near the seafloor.
- **Limitations in models:** Unable to capture the energy loss from eddies to smaller-scales, e.g., no **lee waves**.





Nikurashin et al. (2013)

Energy loss from eddies due to lee wave generation



0.04 TW

0.12 TW

0.05 TW

- **Lee waves are a large energy sink to the eddy flow.**

Yang et al., under review

Research Goals

Ultimate goal: To understand the role of **lee wave drag and lee-wave-driven mixing** for the response of the Southern Ocean circulation to the changing wind.

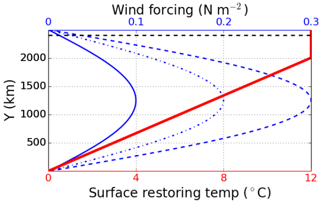
$$\boldsymbol{\tau}_{\mathrm{LW}} = -\frac{1}{2}\rho_o \cdot \boxed{kNH^2} \cdot \mathbf{u}$$

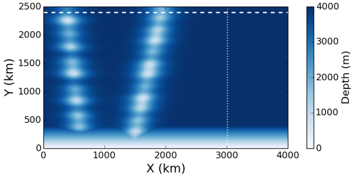
Intermediate step: To explore the impacts of **bottom frictional drag** on the sensitivity of the Southern Ocean circulation to the varying wind stress.

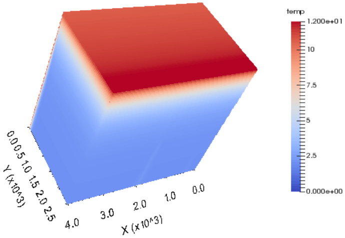
$$\boldsymbol{\tau}_{\mathrm{TBBL}} = -\rho_o \cdot \boxed{C_d|\mathbf{u}|} \cdot \mathbf{u}$$

MOM6 Configuration

- Resolution: horizontal dx = 10 km, vertical dz = 5 ∼ 98 m, 72 layers
- Sponge: 2400 km ⩽ Y ⩽ 2500 km, restored to a exponential temperature profile at northern boundary





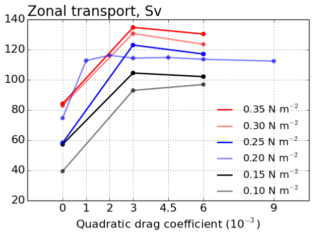


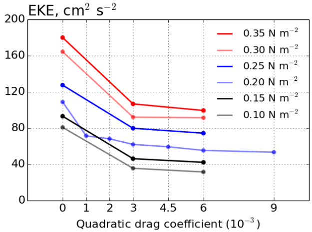
Experiments

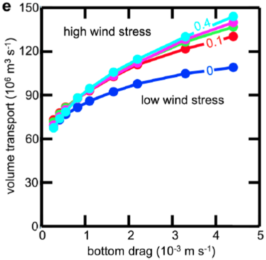
Experiments: We use an idealised channel configuration for the wind perturbation experiments.

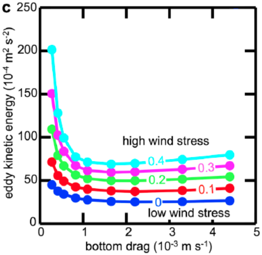
Wind stress (N m^{-2})	0.10	0.15	0.20	0.25	0.30	0.35	
No drag, C_d=0	X	X	X	X	X	X	**none**
Linear,	X	X	X	X	X	X	**lin**
Quadratic, $C_d=1\times10^{-3}$			X				
Quadratic, $C_d=2\times10^{-3}$			X				
Quadratic, $C_d=3\times10^{-3}$	X	X	X	X	X	X	**Cd**
Quadratic, $C_d=4.5\times10^{-3}$			X				
Quadratic, $C_d=6\times10^{-3}$	X	X	X	X	X	X	**2·Cd**
Quadratic, $C_d=9\times10^{-3}$			X				

Results: Zonal transport









Marshall et al. (2017)

Marshall et al. (2017) theory → **baroclinic** transport

- Eddy energy source

$$\alpha_2 \frac{|f|}{N} \frac{\partial u}{\partial z} \int_{-H}^{0} E dz$$

- Eddy energy sink

$$\lambda \int_{-H}^{0} E dz$$

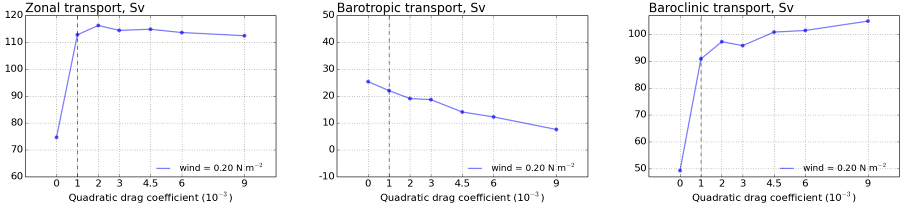
- Eddy energy balance

$$\alpha_2 \frac{|f|}{N} \frac{\partial u}{\partial z} = \lambda$$

- (Baroclinic) Volume transport

$$\mathbf{T} = \lambda \frac{N}{|f|} \frac{H^2 L}{2\alpha_2}$$

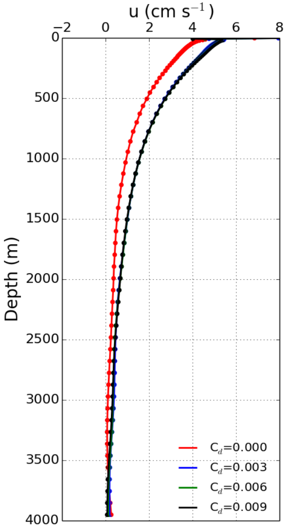
Results: Total transport = Barotropic + Baroclinic

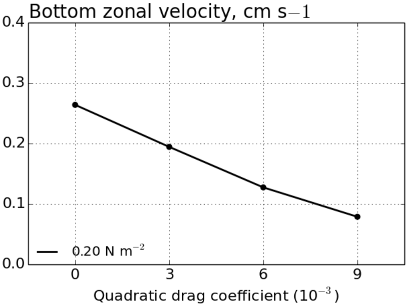


New finding compared with Marshall et al. (2017) is that,

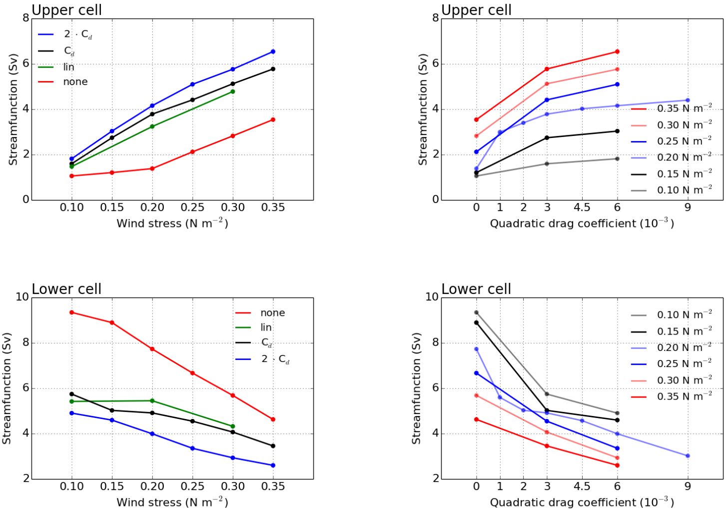
the total transport is rather **insensitive** to bottom frictional drag for large drag coefficient, which arises from the **cancellation** between the increase in the baroclinic transport [consistent with Marshall et al.] and the decrease in the barotropic transport.

Results: Barotropic vs. Baroclinic



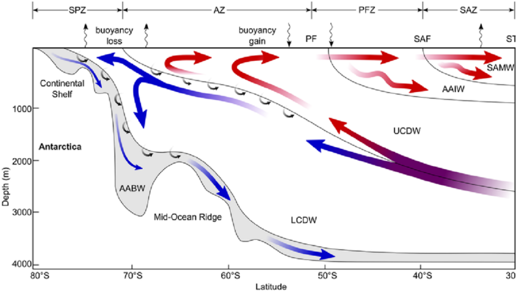


Results: Overturning circulation



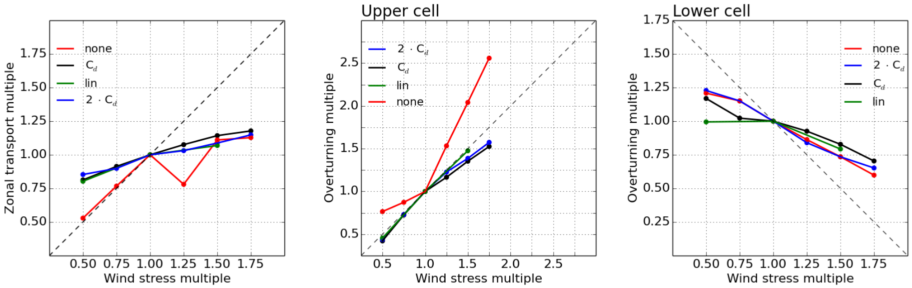
Overturning circulation

	Wind-driven	Eddy-driven	Residual
Upper	+++++	- -	+++
Lower	++	- - - - -	- - -



Adapted from Speer et al. 2000

Results: Sensitivity



- The insensitivity is indicated by a horizontal line lying at multiple = 1.
- Overturning is more sensitive to wind than zonal transport [consistent with previous studies, e.g. Morrison and Hogg 2013].
- The sensitivity of zonal transport and overturning do not vary under different choices of C_d; however, the presence of drag makes a difference!

Summary

- Simulated zonal transport and overturning cells **respond to** changes made to **bottom frictional drag**, which regulates the strength of the simulated **eddy field** and therefore the sensitivity of the simulated circulation.
  - The total transport increases in the presence of bottom frictional drag and is **insensitive** to the choice of drag coefficient.
  - The sensitivity of the total ACC transport to bottom frictional drag is controlled by both its **baroclinic (dominant)** and **barotropic (non-negligible)** components.
  - The increase in drag coefficient leads to a weaker eddy-driven overturning and therefore **strengthens** upper cell and **weakens** the lower cell.
  - **The presence of drag** affects the sensitivity of zonal transport and overturning to wind, although the choices of drag coefficient do not matter.

Future Work

Our future work is to parameterize **lee wave drag**, and add an **energetically consistent mixing** near the bottom inside the model, where the sensitivity of the Southern Ocean circulation will be re-evaluated.

Results: Overturning circulation

Wind stress = 0.2 N m^{-2}