“Wind-driven” Antarctic Circumpolar Current (ACC)

Upper & lower overturning cells

Buoyancy fluxes also drive circulation
Southern connections to global overturning

- Upper (NADW) cell – partly wind-driven?
- Lower (AABW) cell – balance between interior mixing and southern buoyancy fluxes

**Today’s talk:** Review how (and why) the upper & lower cells are likely to change with variations in forcing – both wind stress and surface buoyancy flux.
The Upper Cell: The Basics

1. Wind Stress
2. Ekman Transport
3. Isopycnals Tilted Upwards
4. Eddies relax isopycnals

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(i) Theory: Residual Mean

![Diagram showing the flow with residual mean, eddy, and wind stress forcing.](Image)

- Can divide flow into a mean, eddy and residual overturning.
- Eddy overturning “opposes” the mean

Insensitivity of upper MOC cell to wind stress forcing:
- **Eddy compensation**

Insensitivity of ACC to wind stress forcing:
- **Eddy saturation**

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A “simple” model to explore MOC dynamics

Zonally averaged, layer averaged zonal transport:

\[ T = \int_0^{L_y} hu \, dy \equiv \langle hu \rangle \]

\[ T_t \approx f\langle hv \rangle - \langle hM_x \rangle + \langle \tau \rangle \]

Eddies modify both the meridional transport and the form stress terms.

If you want to follow the maths, read Killworth & Nanneh, JPO (1994). See also Howard et al., JPO (2014)
(ii) Observations: Sensitivity of Eddies

Satellite observations now confirm that eddy KE has increasing with the wind.

Hogg et al., JGR (2015)
(iii) Models: Sensitivity of MOC to Eddies

Farneti et al., JPO (2010)
Coarse-resolution models have weak compensation, unless GM coefficient is variable (e.g. Gent & Danabasoglu, J. Climate, 2011)
We have known for sometime that buoyancy gain is an important aspect of the Southern overturning . . . in fact, overturning can be diagnosed from buoyancy fluxes (Badin et al., JPO, 2013)
(iv) Complications: Sensitivity to Buoyancy

Morrison et al., GRL (2011)

[Equivalently, the overturning response to wind depends upon surface BC (Abernathey et al., JPO, 2011)]
(iv) Complications: What is an eddy?

- **Standing eddies** can actually explain a significant component of the overturning circulation.

- Standing eddies may also control the location of heat fluxes (Abernathey & Cessi, JPO, 2014)

- Standing meander response to forcing is also important (Thompson & Naveira Garabato, JPO, 2014)
(iv) Complications: Three-dimensionality

- ACC is non-zonal
- No guarantee that a 2D representation of overturning is relevant to transport of tracers!
Meridional Overturning in the Southern Ocean

Andy Hogg

The Southern Ocean

Upper Cell
(i) Theory
(ii) Observations
(iii) Models
(iv) Complications

Lower Cell
(i) The Basics
(ii) Observations
(iii) Models
(iv) Complications

Conclusions

From Talley (adapted from NRC, 2011)
What sets the strength of the lower cell?

- Available Potential Energy input from surface buoyancy fluxes (Hughes et al., JPO, 2006)
- Entrainment of the descending plume (Hughes & Griffiths, Ocean Mod., 2006)
- Interior mixing . . . (Nikurashin & Ferrari, GRL, 2013)
- . . . as well as lateral eddy fluxes (Ito & Marshall, JPO, 2008)
- All of the above?
(ii) Observations: Warming & Freshening

Purkey & Johnson, J. Climate, 2012
(iv) Complications

- It is very likely that surface freshening/warming will reduce AABW formation, but is it also sensitive to changes in wind stress?
- Can or should changes in lower cell be offset by changes in the upper cell?
- Can we estimate current buoyancy fluxes close to the Antarctic coast? (see Tamura et al., GRL 2008)
- The lower cell is potentially more important to the carbon cycle than the upper cell, but can we even estimate the carbon uptake in these regions?
- How can we model all the processes involved in bottom water formation?
Conclusions

Upper Cell

▶ Upwelling in the Southern Ocean is predominantly driven by wind;
▶ Changes in wind stress may be partially compensated by eddies;
▶ Net overturning may be more sensitive to buoyancy changes than wind.

Lower Cell

▶ Driven by surface buoyancy fluxes, but many processes are involved.
▶ Poorly modelled, poorly observed.
▶ Contribution to carbon cycle remains uncertain.