Diapycnal and Isopycnal Mixing Experiment in the Southern Ocean

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Southern Ocean and Climate

- Deep water masses come to the surface in the Southern Ocean and exchange heat/carbon with atmosphere.
- Mixing plays a key role in transporting heat, carbon and nutrients in and out of the Southern Ocean along and across isopycnal.

Neutral density (kg m$^3$) section in the Pacific Ocean (WOCE, P16)
• Deep water masses come to the surface in the Southern Ocean and exchange heat/carbon with atmosphere
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Neutral density (kg m$^3$) section in the Pacific Ocean (WOCE, P16)
• Tracer released (107°W, 58°S) on $\rho=27.9$ kg/m$^3$ (1500m) in Feb 2009
• Tracer was sampled on a grid after 1 year and along a few transects after 2, 2.5 years and 3 years

The tracer spread both along and across density surfaces
Diapycnal mixing

- The diapycnal diffusivity is the rate at which the tracer cloud spreads vertically

\[
\kappa \equiv \frac{1}{2} \frac{d}{dt} \left( \frac{\langle (z - z_c)^2 c \rangle}{\langle c \rangle} \right) \approx \frac{1}{2T} \left[ \frac{\langle (z - z_c)^2 c(T) \rangle}{\langle c(T) \rangle} - \frac{\langle (z - z_c)^2 c(0) \rangle}{\langle c(0) \rangle} \right]
\]

- The diapycnal diffusivity is small upstream of Drake Passage \((1 \times 10^{-5} \text{ m}^2/\text{s})\)
  Ledwell et al. (JPO, 2011)

- The diapycnal diffusivity is large downstream of Drake Passage \((40 \times 10^{-5} \text{ m}^2/\text{s})\)
  Watson et al. (Nature, 2013)
Isopycnal diffusivity

- The isopycnal diffusivity is the rate at which the tracer cloud spreads laterally

\[
K \equiv \frac{1}{2} \frac{d}{dt} \left( \frac{\langle (y - y_c)^2 c \rangle}{\langle c \rangle} \right) \approx \frac{1}{2T} \left[ \frac{\langle (y - y_c)^2 c(T) \rangle}{\langle c(T) \rangle} - \frac{\langle (y - y_c)^2 c(0) \rangle}{\langle c(0) \rangle} \right]
\]

- The isopycnal diffusivity upstream of Drake Passage is 710±260 m²/s
  Tulloch, Ferrari et al. (JPO, 2014)
Isopycnal diffusivity: model

- MIT General Circulation Model, 3 km horizontal resolution, 100 vertical levels
- Forced with reanalysis surface fluxes and state estimate at lateral boundaries

θ at 500m

Ali Mashayek
• The DIMES tracer indicate that at 1500m, $K=710\pm260 \text{ m}^2/\text{s}$
• The model tracers indicate that $K$ is less than 500 $\text{m}^2/\text{s}$ in the upper kilometer and reaches 900 $\text{m}^2/\text{s}$ at 2000 m
• The isopycnal diffusivity peaks at the critical level where the eddies drift at the mean flow speed

**Tracer diffusivity**

**GM diffusivity**
Conclusions

- The diapycnal diffusivity is enhanced close to topography in Drake Passage (St. Laurent et al., 2012, Watson et al., 2013)

- The isopycnal diffusivity peaks to 900 m²/s at 2000m, the interface between upper and lower MOC cells (Tulloch et al., 2014; LaCasce et al., 2014)

- The GM diffusivity is uniform and close to 400 m²/s (Mashayek and Ferrari, to be submitted)

- New eddy parameterizations are developed to capture variations of isopycnal diffusivity with depth (Bates, Marshall, Ferrari, 2014)
Vertical structure of $K$

- Eddy mixing is suppressed in the upper kilometer and enhanced at steering levels where $U=c$
- The vertical structure of $K$ is well described by linear theory (Bretherton, 1966; Green, 1970; Ferrari and Nikurashin, 2010)

*Tulloch, Ferrari et many al., submitted*