IMPACT OF SURFACE WIND AND BUOYANCY FORCING ON THE ENERGETICS AND TRANSPORT IN A ROTATING WIND-FORCED HORIZONTAL CONVECTION MODEL OF A REENTRANT CHANNEL

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BLUE WATERS SUSTAINED PETASCALE COMPUTING

Introduction

Zemskova et al (2015) calculated the global ocean energy budget using MITgcm ECCO2 model output to show that conversion of KE to APE through mean wind-driven upwelling is balanced by removal of APE through baroclinic generation of eddies (similar to findings in von Storch et al, 2012; Wolfe and Cessi, 2011). These processes are particularly significant in the Southern Ocean, where both buoyancy forcing though surface cooling and strong surface winds over the ACC are present (Stewart and Thompson, 2012; Abernathey et al, 2011).

Objective: quantify a complete energy budget, down to dissipative scales, in an idealized model with a reentrant channel and surface wind and buoyancy forcing representative of the Southern Ocean.

3D Direct Numerical Simulations: resolve turbulent scales and therefore the energy transfers from the mean wind- and buoyancy-driven overturning, to mesoscale eddies as well as the forward cascade to dissipative scales.

Simulation Set-up

- **SOMAR (Stratified Ocean Model with Adaptive Refinement)**
  - Solves incompressible Navier-Stokes equations with Boussinesq approximation
- **5 simulations:**
  - Buoyancy forcing only
  - Buoyancy forcing plus 4 variable wind forcing profiles
- **Domain size:**
  [5, 10, 1] with resolution (Nx,Ny,Nz)=(512,1024,128)
- **Boundary conditions:**
  - Periodic in zonal (x) direction
  - Dirichlet buoyancy and Neumann u-velocity at the top
  - No buoyancy flux, no-slip elsewhere

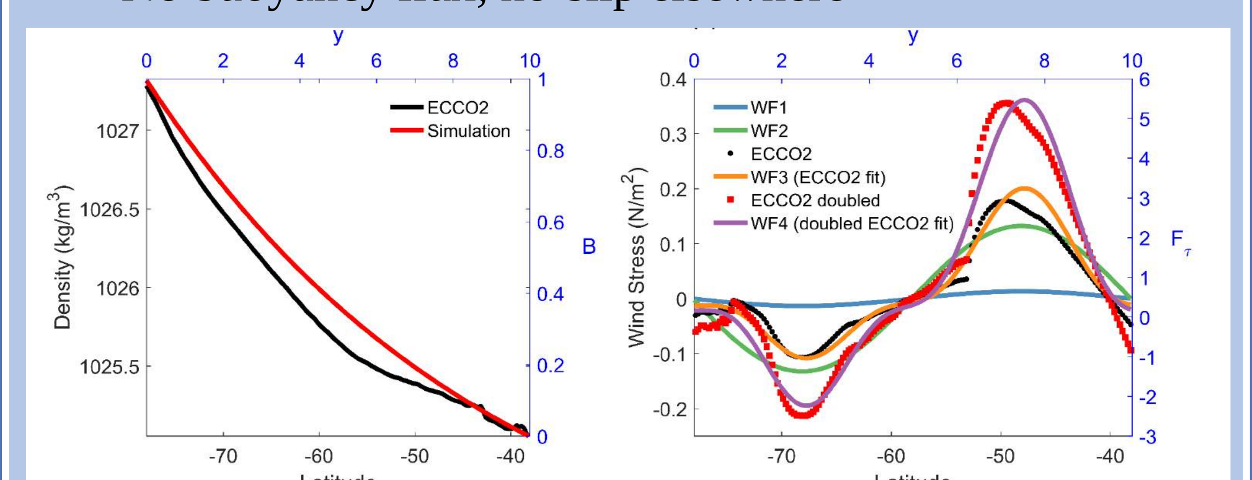


Fig 1: Boundary conditions at the top surface for simulation compared with ocean data from ECCO2 over the area of interest: (top) density distribution, (bottom) wind stress distribution

$$Ra = \frac{b_{max}L^3}{\nu\kappa} = 10^{11} \qquad Ro = \frac{\sqrt{\Delta b H}}{fL} \approx 0.025$$

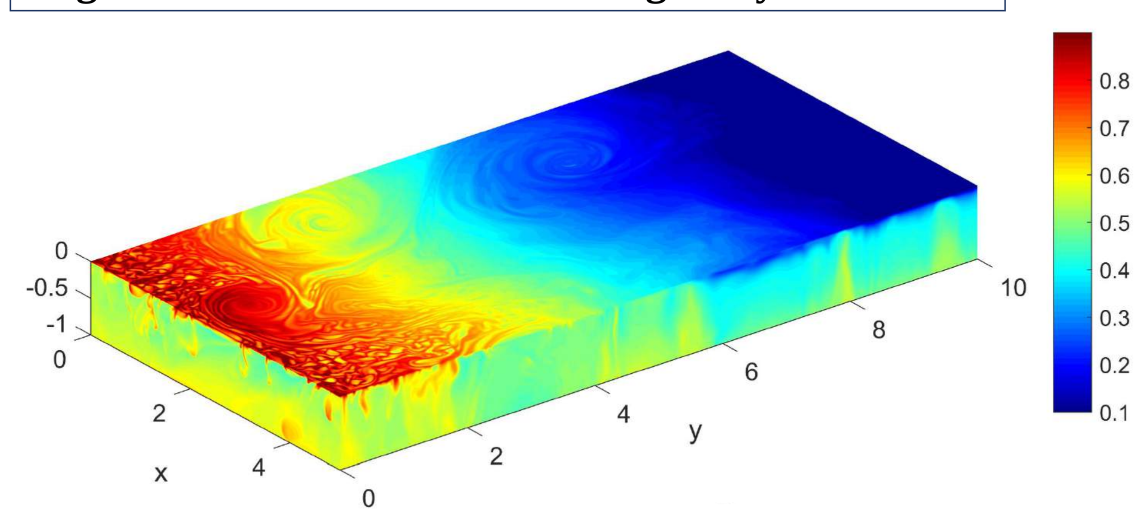
$$Rd = \frac{\sqrt{\Delta b H}}{f} = 0.25 \qquad Re = \frac{H\sqrt{\Delta b H}}{\nu} \approx 3.8 \times 10^3$$

$$Bu = \left(\frac{NH}{fL}\right)^2 \approx 6.3 \times 10^{-4} \qquad Ek = \frac{\nu}{fH^2} \approx 7 \times 10^{-5}$$

$$\tau_{max} = \nu \frac{\partial u}{\partial z}\Big|_{max} \approx 0.013 - 0.35\, N/m^2$$

Results

Fig 1: Instantaneous 3D reduced gravity for WF3.



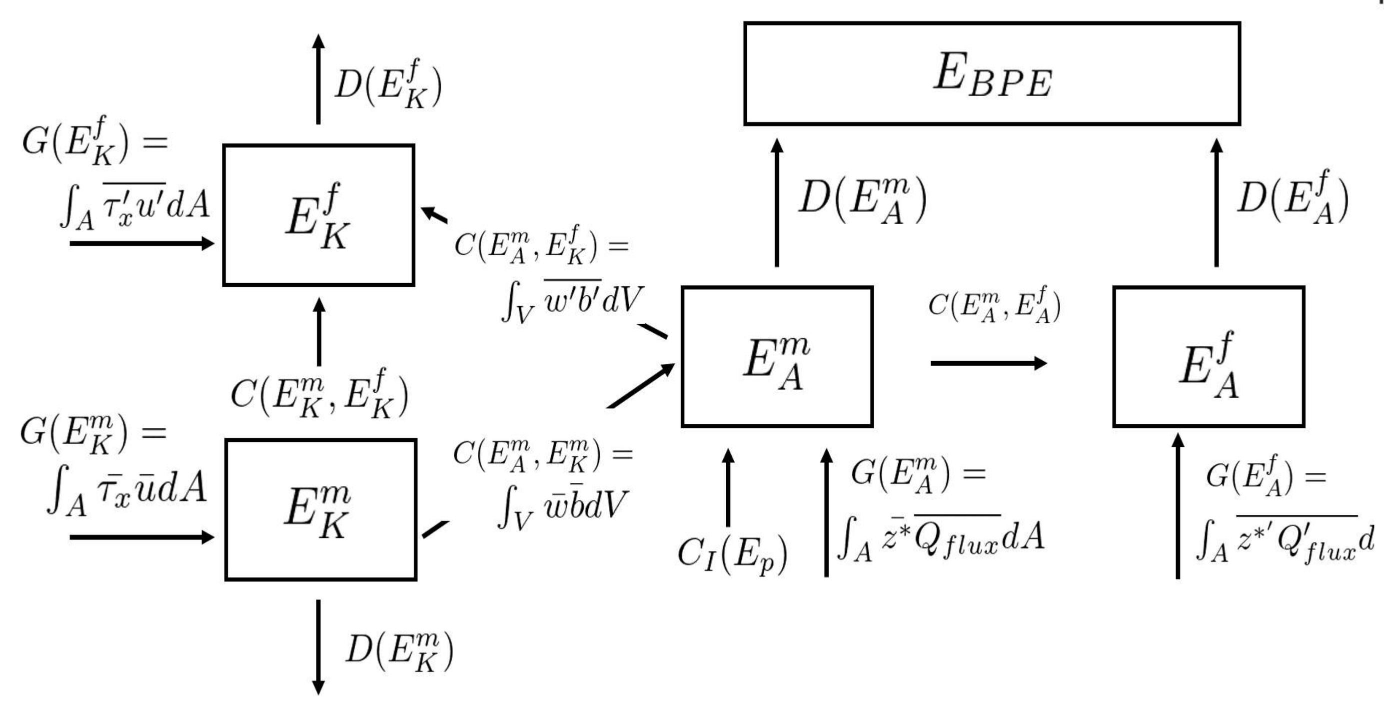


Fig 2: Energy diagram showing sources and sinks of and exchanges between the mean and fluctuating kinetic (KE) and available potential (APE) energy reservoirs.

Zonally and temporally averaged reduced gravity

$$\Psi_{y\rho} = -\frac{1}{\Delta t}\int_t \int \int_{\rho' \leq \rho} v(x,y,z,t)\, dz\, dx\, dt$$

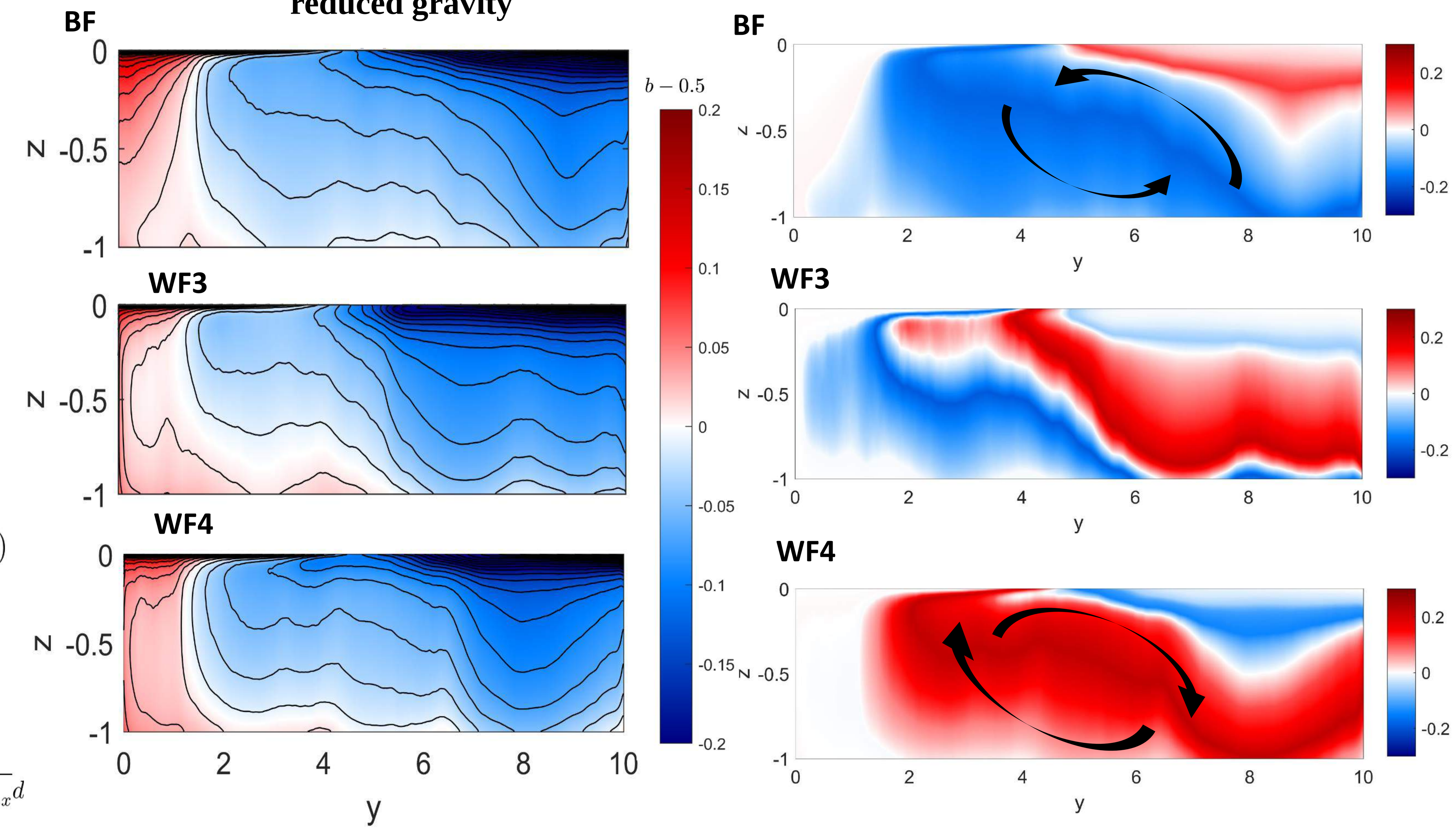


Fig 3: (left) zonally and temporally averaged reduced gravity
(right) residual density-latitude overturning streamfunction (remapped as depth-latitude)

- BF: dominated by buoyancy-driven mechanism of dense water sinking
- WF3: wind-driven clockwise cell pushes further southward
- WF4: strong wind overwhelms the buoyancy-driven deep water formation region

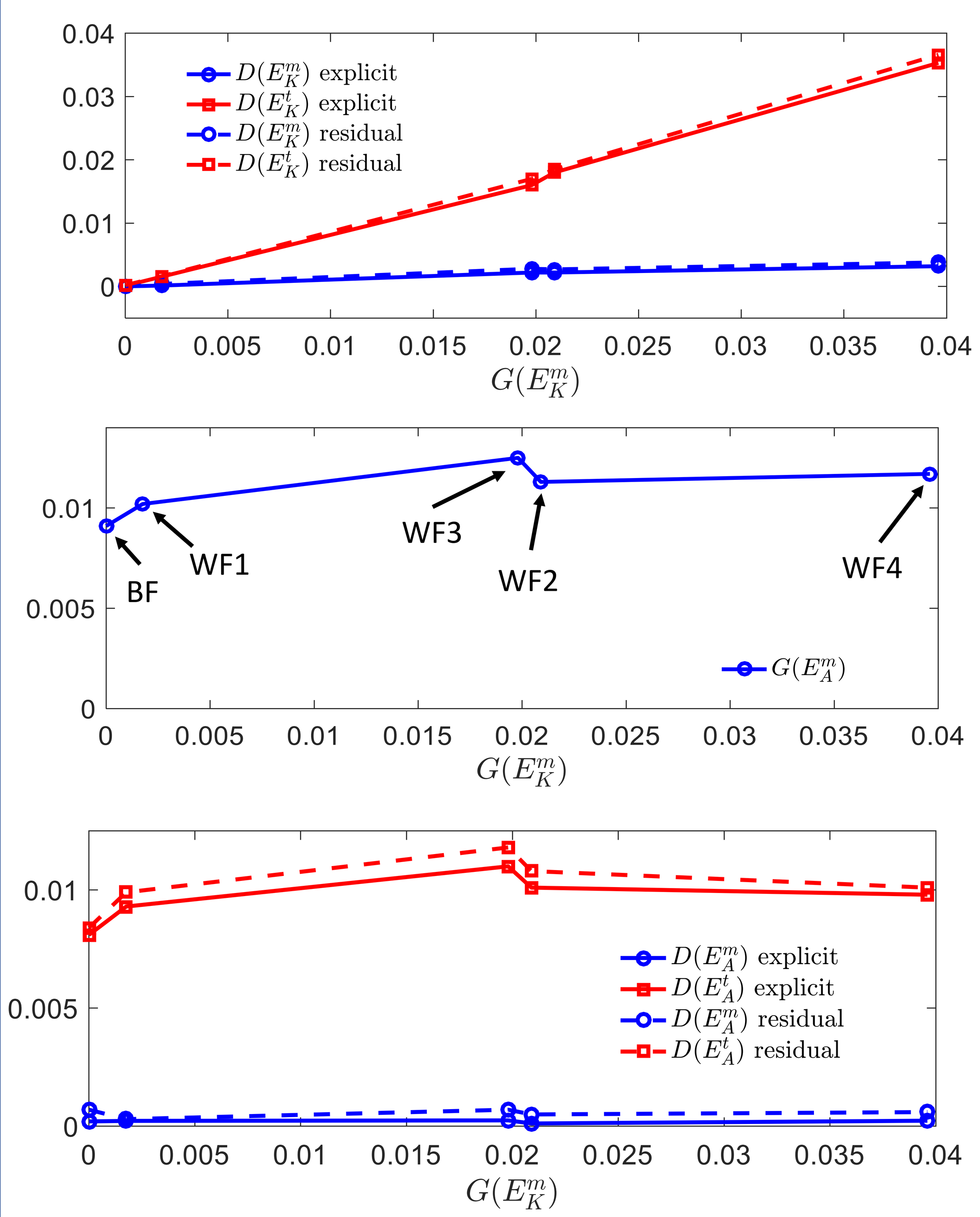


Fig 4: Energy budget terms as a function of KE generation via wind forcing:
(top) KE dissipation (mean and fluctuating)
(middle) APE generation
(bottom) APE dissipation (mean and fluctuating)

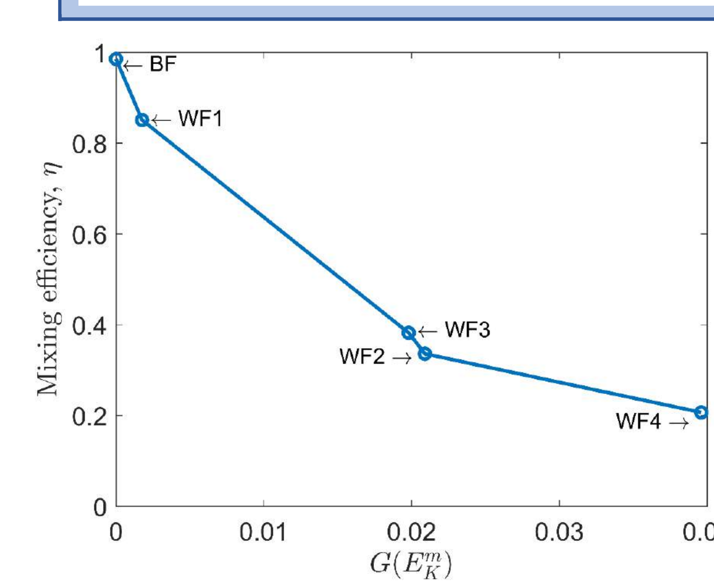


Fig 5: Mixing efficiency

$$\eta = \frac{D(E_A) - C_I(E_P)}{D(E_A) - C_I(E_P) + D(E_K)}$$

as a function of KE generation.

Conclusions

- Major features of the Southern Ocean overturning circulation were reproduced in WF3 (simulation with realistic buoyancy and wind stress surface forcing)
- As wind stress (KE generation) increases:
  - mean and turbulent vertical buoyancy fluxes show primarily eddy compensation;
  - residual overturning streamfunction is sensitive to the surface wind forcing and progresses from buoyancy-driven to mainly wind-driven circulation significantly weakening the lower circulation cell.
- Surface-integrated APE generation and volume-integrated diapycnal mixing are strongly driven by surface buoyancy fluxes that control watermass formation at the surface.
  - However, local diapycnal mixing rates are affected by overturning circulation dynamics that change local stratificaltion.

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