Southern Ocean Ventilation

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Ventilation biases

Long et al. [2013]
Meridional overturning circulation

The diabatic Deacon Cell

After Marshall and Radko, JPO, 2003
Resolved and parameterized transport

Tracer transport

\[ \frac{\partial \varphi}{\partial t} + (u + u^*) \cdot \nabla_h \varphi + (w + w^*) \frac{\partial \varphi}{\partial z} = R(\varphi) + D_V(\varphi) + J(\varphi) \]

Eddy-induced advection

\[ u^* = \left( \kappa_{thic} \frac{\nabla_h \rho}{\rho_z} \right)_z \] and \[ w^* = -\nabla_h \cdot \left( \kappa_{thic} \frac{\nabla_h \rho}{\rho_z} \right) \]

Isopycnal mixing

\[ R(\varphi) = \nabla \cdot \left( \kappa_{iso} \begin{bmatrix} 1 & 0 & -\rho_x/\rho_z \\ 0 & 1 & -\rho_y/\rho_z \\ -\rho_x/\rho_z & -\rho_y/\rho_z & |\nabla_h \rho|^2 / \rho_z^2 \end{bmatrix} \cdot \nabla \varphi \right) \]

\[ \chi_y = \partial X / \partial y \]

\[ \nabla_h = \text{horizontal divergence operator.} \]
Horizontal uniformity in surface layer, attenuation with depth

\[ \kappa = f(x, y, z, t) \]

Boundary layer

Transition layer

Interior

\[ \rho \]

Spatially uniform horizontal mixing

\[ N_{\text{ref}}^2, K_{\text{max}} \]

\[ K(z) = \max \left( \frac{N_{\text{ref}}^2}{N_{\text{ref}}^2}, 0.1 \right) K_{\text{max}} \]

\( \Downarrow \) = Diabatic mixing

:: Parameterization ::
Mechanisms controlling uptake

**Vertical transport within ACC**

- **Eulerian advection**
- **Diapycnal mixing**
- **Bolus**
- **Redi**

- GM-bolus term opposes Eulerian-mean advection;
- Diapycnal mixing and isopycnal diffusion (Redi) dominate transport into the interior.

:: Sensitivity experiments ::
Sensitivity experiments: $\kappa_{iso}$

$\kappa_{iso}$ profile

Southern Ocean mean $\kappa_{iso}$ profile

$\kappa_{iso} \geq 1000$ (z > -1000m)

$\kappa_{iso}$ asympt. = 0.4 × max

$\kappa_{iso}$ asympt. = 0.2 × max

$\kappa_{iso}$ Control

TTT = f(LR × 5)
Sensitivity experiments: $\kappa_{iso}$ (& $\kappa_{thic}$)

pCFC-11 bias (zonal mean section)

pCFC-11 change

- $\kappa_{iso} \uparrow 20\%$
- $\mathrm{TLT} = f(L_R \times 5)$
- $\kappa_{iso} \geq 1000 \ (z > -1000\mathrm{m})$
- $\kappa_{iso}$ assympt. = $0.2 \times \max$
- $\kappa_{iso}$ assympt. = $0.4 \times \max$
Stratification bias

August-October mixed layer depth ($\Delta \sigma_\theta = 0.03$)

Dong et al. 2006
Sensitivity experiments: boundary layer processes

pCFC-11 bias (zonal mean section)

pCFC-11 change

- $k_x \times 2 \ (z > -600m)$
- $\kappa_{iso} \ \text{assympt.} = 0.2 \times \text{max}$
- $k_x \times 10 \ (z > -600m)$
- $\kappa_{iso} \ \text{assympt.} = 0.2 \times \text{max}$

Submesoscale mixing off
Interaction between surface boundary and isopycnal mixing

Southern Ocean mean $\kappa_{iso}$ profile

Control

$k_y \times 10 \ (z > -600 \text{m})$

$\kappa_{iso}$ asympt.

$= 0.2 \times \text{max}$
Seasonal handoff: boundary layer to isopycnal mixing

Vertical fluxes in ACC

:: Sensitivity experiments ::
Vertical transport within ACC

CFC flux [$10^6$ mol yr$^{-1}$]

-6.0 -4.0 -2.0 0.0 2.0 4.0

0.0

Depth [km]

0.0 0.2 0.4 0.6 0.8 1.0

Submeso

Diapycnal mixing

Eulerian advection

Bolus

Redi

Control

min $\kappa \times 0.2$

min $\kappa \times 0.4$

:: Sensitivity experiments ::
Sensitivity experiments: boundary layer processes

Mixed layer depth biases [m]

- Control
- $\text{Ri}_c(0.3 \rightarrow 0.6)$
- Submeso off
- Langmuir v0.0
- $k_v \times 2 \ (z > -600m)$
- $k_v \times 10 \ (z > -600m)$
Large-scale dynamics control mixed layer biases

Control

\[
\text{min } \kappa \times 0.2
\]

\[
\text{min } \kappa \times 0.4
\]

MLD bias/change

:: Sensitivity experiments ::
What is the spatial distribution of eddy diffusivity: $\kappa \sim u_{\text{rms}}L_{\text{mix}}$?

0.1° POP RMS Velocity

$u_{\text{rms}} = \sqrt{\text{EKE}}$
Main points

- Ventilation of AAIW and SAMW in the CESM ocean component is deficient;
- Improvements are realized with enhanced diapycnal or isopycnal mixing, but most responsive to both;
- Depth attenuation in isopycnal mixing scheme is fairly flexible (tune-able) and probably fairly realistic; and
- Spatial variability in lateral mixing at the surface is likely to be a feature of the real ocean: need a theory.