Eulerian and Lagrangian diffusivities in the Southern Ocean of 1/10°POP

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I Intro

- Model
- Deployments
- Method

II Results

- Depth dependence of Lagrangian diffusivities
- Latitude dependence of Lagrangian diffusivities
- How well do Lagrangian diffusivities parameterize model eddy heat transport

III Discussion

- Number of floats
- Lateral Placement
I Parallel Ocean Program Model

- 1/10° horizontal resolution, 2-9 km grid spacing between 79°S - 34°S

- 40 depth levels (10 m - 250 m cell thicknesses)

- Subgridscale mixing: horizontal: biharmonic diffusion for tracers and momentum. vertical: KPP


- NCEP/NCAR 6 h air-sea heat fluxes and evaporation, monthly ISCCP (shortwave and cloud fraction), MMS (Spencer, 1993) and Xie, Arkin 1997 precipitation

- Restoring to SSS, SST climatology (Steele et al. 2001) under ice, open ocean SSS restoring with timescale of 6 months (Maltrud and McClean, 2005)
I Numerical float deployments and trajectories

- release in 4 patches
- 300 m, 800 m and 1500 m
- two groups per patch and depth, deployed 60 days apart with 80 floats each
- initial deployment grid: quarter degree spacing
- floats are advected by model flow

Float trajectories from 300 m deployments after ca. 3 years
\begin{align*}
\langle u'_i(x, t) \Theta'(x, t) \rangle &= - \int_0^t d\tau \partial_\tau \kappa_{ij}(x, \tau) \partial_{x_j} \Theta(x, t - \tau) \\
\kappa_{ij}(x, \tau) &= \int_{-\tau}^0 d\tilde{\tau} \langle u'_i(t_0 | x, t_0) u'_j(t_0 + \tilde{\tau} | x, t_0) \rangle_L \\
\tau \rightarrow \infty : \quad \langle u'_i(x, t) \Theta'(x, t) \rangle &= - \kappa_{ij}(x) \partial_{x_j} \Theta(x, t)
\end{align*}

1 Defining Means

\[ v'_E = u_f(x, t) - V_E(x, t) \]
\[ v'_L = u_f(x, t) - V_L(t) \]

1/10° 1998-1999 mean meridional velocity in one bin \([cm/s]\)

\[ \overline{v}_E = (-2.26 \pm 4.04) cm/s \quad \overline{v}_L = (-1.73 \pm 3.23) cm/s \]
I Patch 3 trajectories 1500 m Deployment

Bins:
10° in longitude
5° in latitude

at time of deployment $t=0$:

$27.66 < \sigma_\theta < 27.76$

average over all float trajectories:

$\sigma_\theta(1500m) = 34.653 \pm 0.046$

$\sigma_\theta(0m) = 27.701 \pm 0.040$

$\Delta z \approx (1500 \pm 500)m$
**II Patch 3: Deployment Depth 1500m D1 vs D2**

**Deployment 1**

$k_{yy}$ as a function of time lag with 2 sigma errorbars (100 x jackknife)

Latitude: 57.5°S, Longitudes: 175°W - 95°W
II Patch 3: Deployment Depth 1500m D1 vs D2

Deployment 1  Deployment 2

$\kappa_{yy}$ as a function of time lag with 2 sigma errorbars (100 x jackknife)
Latitude: 57.5°S, Longitudes: 175°W - 95°W
II Patch 3: Deployment 1 Depths 1500 m-300 m

1500 m

\(\kappa_{yy}\) as a function of time lag with 2 sigma errorbars (100 x jackknife)
Latitude: 57.5°S, Longitudes: 175°W - 95°W
II Patch 3: Deployment 1 Depths 1500 m-300 m

1500 m 800 m

$\kappa_{yy}$ as a function of time lag with 2 sigma errorbars (100 x jackknife)
Latitude: 57.5°S, Longitudes: 175°W - 95°W

\begin{align*}
\begin{array}{c}
\kappa_{yy} [m^2/s] \\
-95 & -50 & 0 & 50 & 95 \\
-4000 & -2000 & 0 & 2000 & 4000 \\
\end{array}
\end{align*}

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II Patch 3: Deployment 1 Depths 1500 m-300 m

$\kappa_{yy}$ as a function of time lag with 2 sigma errorbars (100 x jackknife)
Latitude: 57.5°S, Longitudes: 175°W - 95°W
Lagrangian diffusivities with depth

$\kappa_{yy}$ as an average over last 25 tlags (days 70-95), bins at 57.5°S
Lagrangian diffusivities with depth

\( \kappa_{yy} \) as an average over last 25 tlags (days 70-95)
\( \kappa_{yy} \): 1x Standard deviation last 25 tlags, Mean depth in bin: Standard error

\[ + D_1 \circ D_2 \]

- 300m
- 800m
- 1500m

Lagrangian KYY [m^2/s]

Depth [m]
\( \kappa_{yy} \): 1x Standard deviation last 25 tlags, Mean depth in bin: Standard error
Lagrangian diffusivities with latitude

\[ \kappa_{yy} \text{ as an average over last 25 tlags (days 70-95) and longitudes West of Drake Passage} \]
II Lagrangian diffusivities with latitude

\[ \kappa_{yy} \text{ as an average over last 25 tlags (days 70-95) and longitudes West of Drake Passage} \]

Mean depth of trajectories in bin
II Lagrangian diffusivities with latitude

\[ \kappa_{yy} \] as an average over last 25 tlags (days 70-95) and longitudes West of Drake Passage

Zonal mean meridional eddy heat transport
Zonal mean meridional T gradient at 300 m
How well do Lagrangian diffusivities parameterize model eddy heat transport?

- $v'T' = \overline{vT} - \overline{vT}$, overline is 1998-1999 mean
- Interpolate $v'T'$ and $\partial_y \overline{T}$ to drifter locations
- Average over bin
- $\kappa_{EFG} = \langle v'T' \rangle / \langle \partial_y \overline{T} \rangle$
- Eliminate rotational part: $\kappa_{EDL} = \langle \nabla \cdot v'T' \rangle / \langle \nabla^2 \overline{T} \rangle$

FG: "Flux Gradient"
DL: "Divergence Laplacian"
II Lagrangian vs Eulerian diffusivities

\[ \kappa_E = \langle \nu' T' \rangle / \langle \partial_y T \rangle \]

\[ \kappa_E = \langle \nu' T' / \partial_y T \rangle \]
\[ \kappa_E = \frac{\langle \nabla \cdot \overline{v'T'} \rangle}{\langle \nabla^2 T \rangle} \]
Lagrangian vs Eulerian diffusivities - depth dependence

\[ \kappa_{EFG} = \frac{\langle \nabla \cdot \bar{v}'T' \rangle}{\langle \nabla^2 T \rangle} \quad \kappa_{EDL} = \frac{\langle \nabla \cdot \bar{v}'T' \rangle}{\langle \nabla^2 T \rangle} \]
- Lagrangian diffusivity tensor $k_{yy}, k_{xx}, k_{xy}, k_{yx}$, no convergence for zonal diffusivities

- still insufficient Lagrangian statistics, influence of shear dispersion

- Davis 1987 theory strictly for passive tracers

- How to interprete Lagrangian diffusivities with respect to diffusivities commonly used in models (distinguish between diffusive, advective, rotational parts)

$$K_s = \begin{pmatrix}
A & 0 & (A - \kappa_{gm})S_x \\
0 & A & (A - \kappa_{gm})S_y \\
(A + \kappa_{gm})S_x & (A + \kappa_{gm})S_y & AS^2
\end{pmatrix}$$

$$S = -\nabla_h \rho / \partial_z \rho.$$
Summary

- reasonable convergence of diffusivities for 1500 m deployment
- subtraction of spatially varying mean is crucial
- Lagrangian diffusivities \((1719 \pm 1420)m^2/s\) above 500 m, \((972 \pm 548)m^2/s\) at 1250 m
- Latitudinal dependence: Lagrangian diffusivities high where temperature gradients and eddy heat fluxes high
- no correlation between Eulerian and Lagrangian diffusivities, depth dependence is similar
- Parameterization with Lagrangian diffusivities overestimates meridional eddy heat transport and divergence of eddy heat transport across bins by a factor of about 2
Number of Floats 800m deployment

Meridional diffusivity ($m^2/s$) as a function of timelag (days).
Bootstrap 100 times Half the floats (40)
Meridional diffusivity ($m^2/s$) as a function of timelag (days).

Bootstrap 100 times Half the floats (40)
Meridional diffusivity ($m^2/s$) as a function of timelag (days).

Bootstrap 100 times Half the floats (40) Quarter of the floats (20)
Number of Floats 800m deployment

Meridional diffusivity ($m^2/s$) as a function of timelag (days).
Bootstrap 100 times Half the floats (40) Quarter of the floats (20)
Lateral Placement 800m deployment

Left: 40 trajectories from northern side of deployment points. Right: 40 trajectories from southern side
Lateral Placement 800m deployment

Meridional diffusivity \((m^2/s)\) as a function of timelag (days). Sample 100 times Northern set of floats (red) and Southern set of floats (blue). Full sample (black).