Updates on the Lagrangian Analysis with the POP floats

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Near-surface eddy diffusivities in the SO

Along-streamline average as a function of latitude:

Marshall et al. (2002) $\kappa_{eff}$
Near-surface eddy diffusivities in the SO

Along-streamline average as a function of latitude:

Marshall et al. (2002) $\kappa_{\text{eff}}$

Sallee et al. (2008) $\kappa_L$
Near-surface eddy diffusivities in the SO

Along-streamline average as a function of latitude:

Marshall et al. (2002) $\kappa_{\text{eff}}$

Sallee et al. (2008) $\kappa_L$

Horizontal distributions $\kappa_\perp \propto \text{EKE}$ Sallee et al. (2008)
Depth dependence

Maximum at ~1500 m

- Baroclinically unstable jet
- Treguier (1999)
- flux/gradient

Effective diffusivity in SOSE
- Abernathy et al. (2009)
Depth dependence

Maximum at ~1500 m

Baroclinically unstable jet
Treguier (1999)

flux/gradient

Decrease with depth?

Effective diffusivity in SOSE
Abernathy et al. (2009)

Eden (2006) flux/gradient

Johnson, Bryden (1989)

$k(z) = eke(z)$?
EKE vs “Mixing Barriers”

\[ \kappa \propto U_e L_e, \quad \kappa \propto \sqrt{EKE}/(U_m - c) \]


- Strong (PV) gradients, strong mean flow inhibit mixing, leading to small eddy length scales

- Mixing is strong where EKE, eddy fluxes, SSH variability are enhanced

What dominates?
What are typical Lagrangian diffusivities in the model ACC region? Does diffusivity exist?

Challenges:
1) mean subtraction and streamline projection
2) presence of rotational components

What are horizontal and vertical distributions and do these distributions reconcile with existing hypotheses?
Horizontal trajectories from all deployments

- POP: 1/10° horizontal, 40 levels
- spin-up 14 years
- run w’ realistic forcing 1994-2003
- release in 4 patches
- 300 m, 800 m and 1500 m
- initial deployment grid: 1/4° spacing
- deployed 1-1-1999
- floats are advected by model flow
Lagrangian Diffusivity

Variance of particle displacements \( \longrightarrow \) integral of velocity autocovariance

\[
\kappa(\tau) = \frac{1}{2} d_t \langle (y'(\tau) - y'(0))^2 \rangle = \int_0^t \langle v'(t + \tau)v'(t) \rangle dt
\]

\[
\kappa^\infty = \lim_{\tau \to \infty} \kappa(\tau)
\]

Taylor (1921), Davis (1987, 1991)
Means and Coordinate Orientation

P3, 300 m:
2-year
Eulerian mean velocity
\[ u' = u_f - u_e \]
\[ v' = v_f - v_e \]
Means and Coordinate Orientation

P3, 300 m:
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Dispersion (km^2) is non-isotropic

along \( \vec{u}_e \) no mean
Means and Coordinate Orientation

P3, 300 m:
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Dispersion (km\(^2\)) is non-isotropic

along \( \vec{u}_e \) no mean, along \( \vec{u}_e \)
cross \( \vec{u}_e \)
Means and Coordinate Orientation

P3, 300 m:
2-year Eulerian mean velocity

\[ u' = u_f - u_e \]
\[ v' = v_f - v_e \]

Dispersion (km²) is non-isotropic

along \( \vec{u}_e \) no mean, along \( \vec{u}_e \), zonal
cross \( \vec{u}_e \), meridional
Filtered vs unfiltered barotropic streamlines

Now: subtract and project across (spatially highly varying) Eulerian velocities. Ensures cross-stream dispersion by mean is zero.
Patch 1: Long-time Dispersion compared to $\langle d'^2 \rangle_{Taylor} = 2\kappa(100d)\tau$

cross-stream

along-stream
Patch 2: Long-time Dispersion compared to $\langle d'^2 \rangle_{Taylor} = 2\kappa(100d)\tau$

- **a)** $\perp$ P2 300m
- **b)** $\parallel$ P2 300m
- **c)** $\perp$ P2 800m
- **d)** $\parallel$ P2 800m
- **e)** $\perp$ P2 1500m
- **f)** $\parallel$ P2 1500m
Long-time Dispersion P3

Patch 3: Long-time Dispersion compared to $\langle d'^2 \rangle_{Taylor} = 2\kappa(100d)\tau$

cross-stream

along-stream
Long-time Dispersion P4

Patch 4: Long-time Dispersion compared to $\langle d'^2 \rangle_{\text{Taylor}} = 2\kappa(100d)\tau$

\[ \text{cross-stream} \quad \text{along-stream} \]
Long-time Diffusivities

- **a)** \(\perp\) Patch 1
- **b)** \(\perp\) Patch 2
- **c)** \(\perp\) Patch 3
- **d)** \(\perp\) Patch 4
- **e)** \(\parallel\) Patch 1
- **f)** \(\parallel\) Patch 2
- **g)** \(\parallel\) Patch 3
- **h)** \(\parallel\) Patch 4

**Axes:**
- \(\kappa_{\perp} (m^2/s)\)
- \(\kappa_{\parallel} (m^2/s)\)
- Time lag (days)

**Dimensions:**
- 300 m, 800 m, 1500 m
- 0, 5000, 10000, 15000, 20000
- 0, 10000, 20000, 30000, 40000

**Colors:**
- Black, red, blue, gray
Long-time diffusivities

Diffusivities as a function of time lag from 2-year long trajectories
Long-time diffusivities

Diffusivities as a function of time lag from 2-year long trajectories

\[ \kappa_{\perp} \quad 300 \text{ m} \quad 800 \text{ m} \quad 1500 \text{ m} \]

\[ \kappa_{\parallel} \quad 0 \quad 50 \quad 100 \]

\[ \kappa_{\perp} \quad 0 \quad 250 \quad 500 \quad 750 \quad 1000 \]

\[ \kappa_{\parallel} \quad 0 \quad 5000 \quad 10000 \quad 15000 \]

\[ \kappa_{max} \neq \kappa_{\infty} \]
meandering and circling trajectories

Diffusivities

- Rotational Parts
meandering and circling trajectories

Diffusivities

Berloff et al. (2002), Veneziani et al. (2004, 2005)
Binned Diffusivities as a function of time lag

Now bin trajectories: $10^\circ$ longitude x filtered barotropic streamlines in latitude
For Patch 4, bins around Drake Passage at Polar Frontal Zone

Cross-stream

\[ \kappa_{\perp} \text{[m}^2\text{s}] \]

\[ \text{time lag [days]} \]

\[ -95 \rightarrow 95 \]

\[ \text{300m} \quad \text{800m} \quad \text{1500m} \]
Binned Diffusivities as a function of time lag

Now bin trajectories: 10° longitude x filtered barotropic streamlines in latitude
For Patch 4, bins around Drake Passage at Polar Frontal Zone
Along-stream
Horizontal distributions

Bin trajectories in $10^\circ$ longitude X barotropic streamline

Diffusivities from 800 m deployments
Depth Dependence: Cross-stream

cross-stream:

\[ \kappa = u' L_e \]

Diffusivity
depth invariant
around Polar Frontal Zone

eddy velocity
decreasing with depth

Eddy length scale
increasing with depth
Depth Dependence: Cross-along stream

cross-stream:  \[ \kappa = u' L_e \]  
along-stream:
Depth Dependence: Cross-stream $\kappa^\infty - \kappa_{max}$

$\kappa^\infty$: $\kappa = u'L_e$

$\kappa_{max}$

Depth dependence plots showing $\kappa$, $u'$, and $L_e$ as functions of depth.
What determines the horizontal distribution of $\kappa_\perp = u' L_e$?
What determines the horizontal distribution of $\kappa_\perp = u' L_e$?

$\kappa^\infty_\perp$:

$L_e$ dominates horizontal distribution

$\kappa^{\max}_\perp$:

$u'$ dominates horizontal distribution
Small values of $\kappa_\perp$ tend to be towards higher $U_m$. Compare to Shuckburgh et al. (2008)
Lagrangian - Eulerian: Depth dependence

Around Polar Frontal Zone  \( \kappa_E = \frac{\langle u' T' \parallel \rangle}{\langle \nabla T \parallel \rangle} \)
Lessons learned?

- The method of computation (projection, mean, time lag) matters.
- With long enough time lags and projection across $u_E(x, y, z)$, the cross-stream diffusive limit can be reached.
- $\kappa_L$ is horizontally highly inhomogeneous.
- The along-streamline average is typically between 500-1000 m$^2$s$^{-1}$ around PF.
- Reduced dominance of correlation with EKE, identify mixing barriers.
- $\kappa_L$ cannot be determined from EKE($z$).
- But also no strong evidence of enhancement at depth except that eddy length scales do increase with depth.
- Challenges for OBS data: identify appropriate mean streamlines/mean velocities.
  - Make sure cross-stream dispersion by mean is zero.