How well do Lagrangian diffusivities parameterize the effects of eddies in the Southern Ocean of 1/10° POP?

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Objective

• Lagrangian floats have been widely used to infer eddy diffusivities in the ocean based on a generalization of Taylor’s classical dispersion theory
• Here, Lagrangian eddy diffusivities are measured by subsurface numerical floats, released in several regions of the 1/10 Parallel Ocean Program (POP) model ACC.
• The objective is to quantify how well these diffusivities, employed in downgradient parameterizations, represent the effect of eddies on the mean heat transport in the model
• A related issue is that the eddy heat flux is comprised of a rotational and divergent component, and only the divergent one influences the mean heat budget
• Therefore, the divergence of the eddy heat flux as well as the raw eddy heat flux are compared with their respective parameterizations

1/10° POP model (Maltrud, Mclean 2005)

• 1/10° horizontal resolution, 2.9 km grid spacing between 90°S-34°S
• 40 depth levels (10 m - 250 m cell thicknesses)
• subgrid-scale 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). MHS (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

Results: Lagrangian diffusivities vs time lag

• Elaborated flux vs gradient law of Davis (1987, 1991): flux of a (passive) tracer from the recent history of its mean concentration

\[ u(x,t) \cdot [\overline{\nabla} f(x,t)] = \int \overline{dY} \overline{u}(x,y) \overline{\nabla} f(x,t) \cdot dY \]  

(1)

• Lagrangian diffusivity: integral of the time lagged Lagrangian velocity autocovariance

\[ \kappa_{yy}(x,t) = \int \overline{dY} \overline{u}(x,y) \overline{u}(x,t) \cdot dY \]  

(2)

• In eddy scales: \( \kappa(\ell, t) \rightarrow \kappa_0 \) in typical advection-diffusion equation

\[ \overline{u}(x,t) \cdot \overline{\nabla} f(x,t) = -\kappa_0 \overline{\nabla} f(x,t) \]  

(3)

• Ideal situation of an ensemble of particles passing through \( x \) at time \( t_0 \) ----- in practice simulated floats passing through a space bin, consider each float observation in bin as deployment point, track float arrival, leaving the point

Results: Eulerian vs Lagrangian diffusivities

• Compute “Eulerian diffusivities”

\[ \nabla \overline{\nabla} \overline{u} \rightarrow \overline{\nabla} \overline{u} \]  

• \( \kappa_{EFL} = \overline{\nabla} \overline{\nabla} \overline{u} \) and \( \kappa_{EDL} \) , eliminate rotational part:

\[ \kappa_{EDL} = \frac{(\nabla \overline{u})^2}{\overline{\nabla} \overline{u}} \]  

Summary and open questions

• 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
• Reasons for discrepancy?
• Distinguish diffusive, advective, rotational parts in both Eulerian and Lagrangian diffusivity tensor
• Still insufficient statistics of Lagrangian floats, influence of shear dispersion
• Temperature is an active tracer and Davis’ theory is for passive tracers