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Mixing Characteristics in a Weakly Energetic, Strongly Stratified Ocean Environment

I - MOTIVATION & OVERVIEW

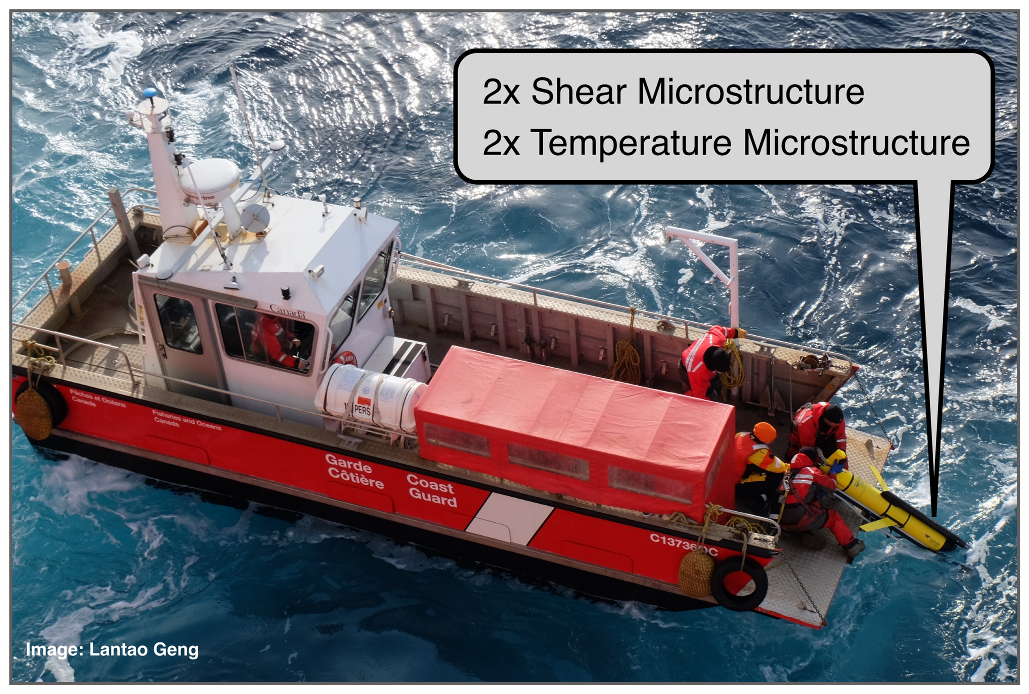
Representations of Ocean Mixing in Regions where Turbulence is Weak and Stratification is Strong

Geophysical flows are often strongly stratified and marginally turbulent—with buoyancy Reynolds number Re_B = O(10) or smaller—and are associated with only weak turbulent diffusivity enhancement. Previous numerical studies (see e.g. Ivey et al. 2008) suggest that the Osborn relation with a constant flux coefficient Γ=0.2 can misrepresent diapycnal mixing in such flows.

Using ocean microstructure measurements, we demonstrate here how predictions given by the Osborn relation systematically diverge from observed tracer fluxes when Re_B becomes small. We further show that, contrary to expectation, the diffusivity remains enhanced by a factor of at least 5 even at exceptionally small values of Re_B = O(10^{-2}).

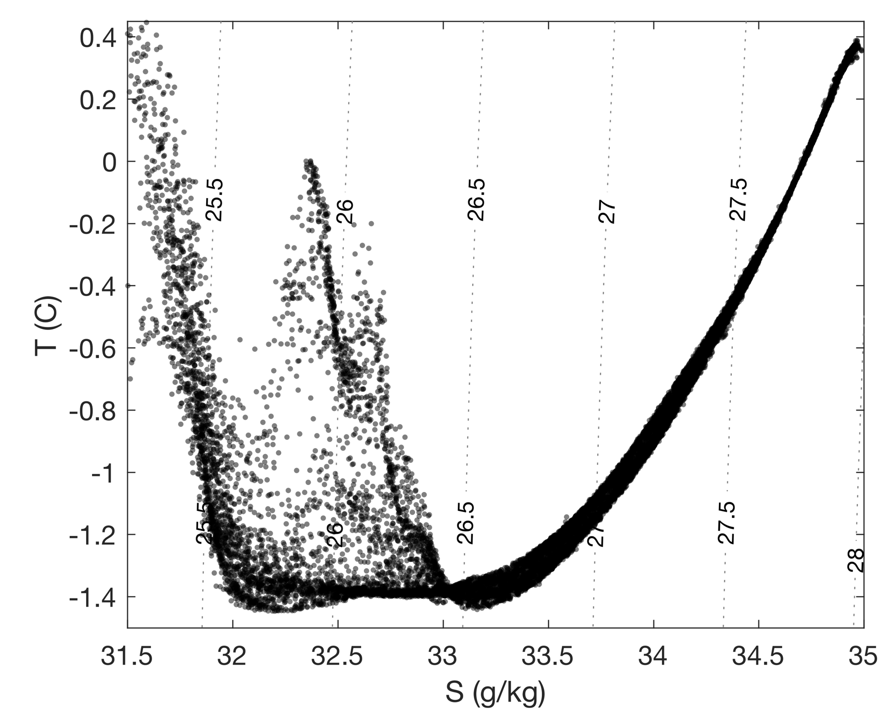
II - OBSERVATIONS & METHODS

Temperature & Shear Microstructure + CTD Measurements from a Glider in the Amundsen Gulf, Beaufort Sea



Temperature and shear microstructure measurements provide coincident, independent estimates of ε, the turbulent dissipation rate.

The Amundsen Gulf in the Beaufort Sea, where we collected the measurements, is a strongly stratified and weakly turbulent ocean environment. Stratification N^2 is typically O(10^{-5}) s^{-2} or O(10^{-4}) s^{-2}.



Left: Temperature-salinity diagram for the available measurements. Note that density contours are ~vertical, implying temperature is a quasi-passive tracer.

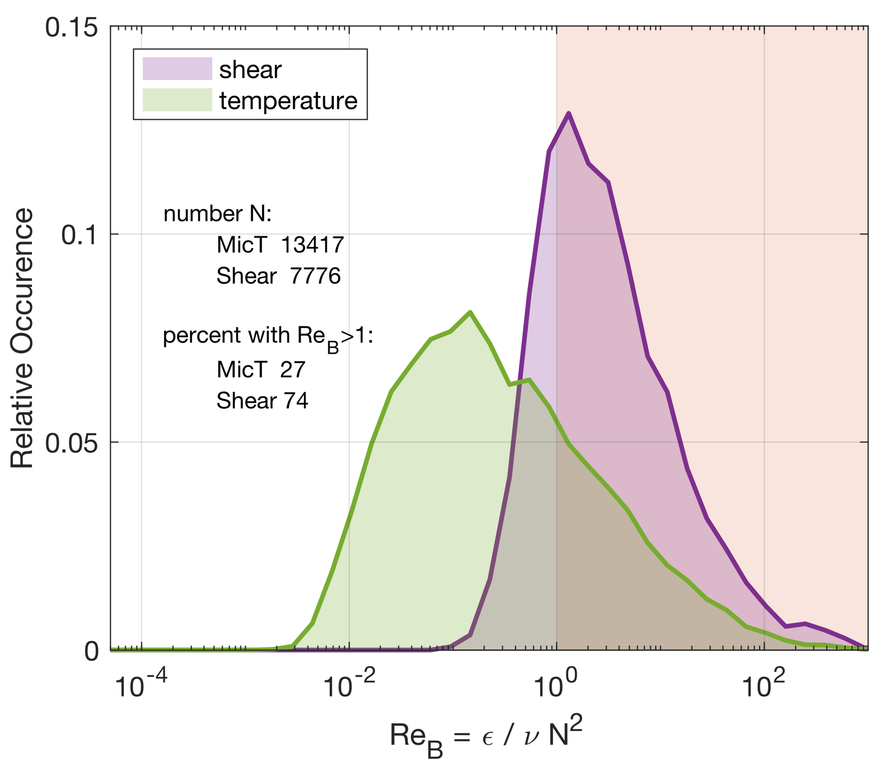
Definitions

Osborn Relation
Turbulent density diffusivity
$$K_\rho = \Gamma \frac{\epsilon}{N^2}$$

Cox Number
Relative strength of turbulent-scale gradients
$$C = \frac{3\left\langle \left(\frac{\partial T'}{\partial x}\right)^2 \right\rangle}{\left(\frac{\Delta \overline{T}}{\Delta x}\right)^2}$$

Osborn-Cox
Turbulent temperature diffusivity
$$K_T = \kappa_T C$$

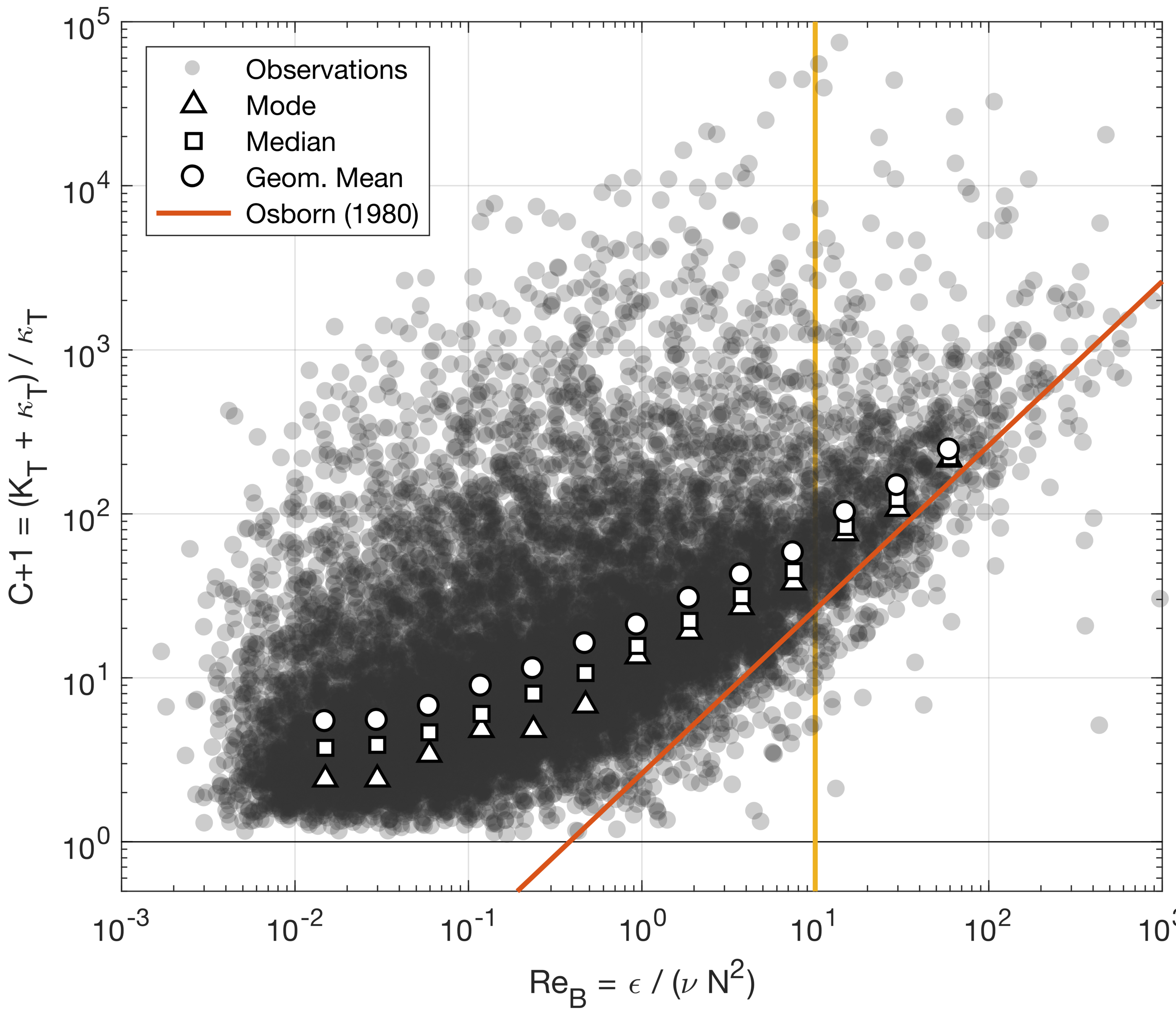
Flux Coefficient
A function of the efficiency, R_f, of turbulent mixing
$$\Gamma = \frac{R_f}{1 + R_f}$$



Left: Distributions of Re_B observations. Shear measurements resolve ε>10^{-10} W/kg; temperature measurements resolve ε>10^{-12} W/kg.

III - RESULTS & DISCUSSION

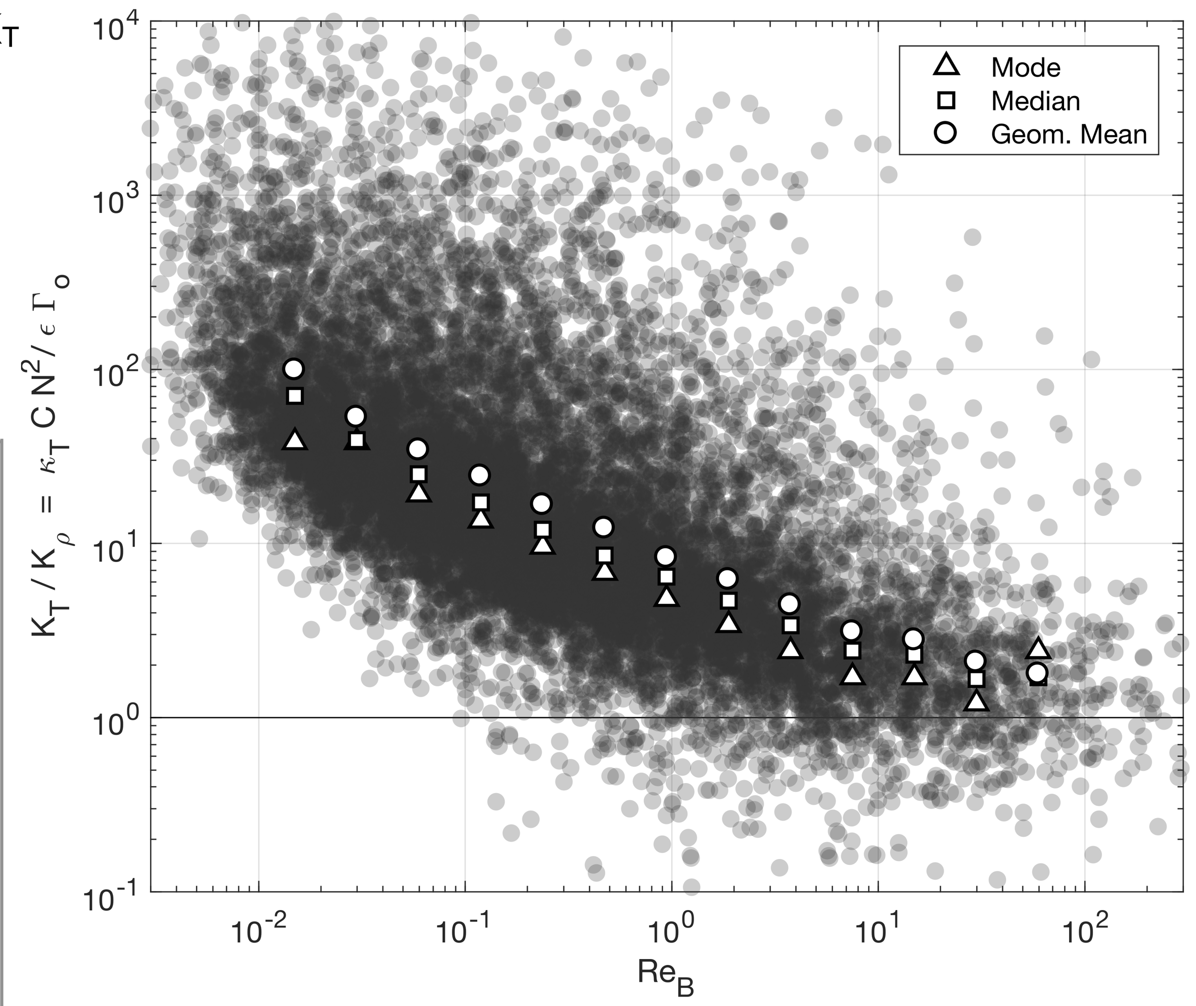
Turbulent Diffusivity Enhancement Diminishes with Decreasing Re_B, Diverges from Standard Osborn Model; Variable Mixing Efficiency



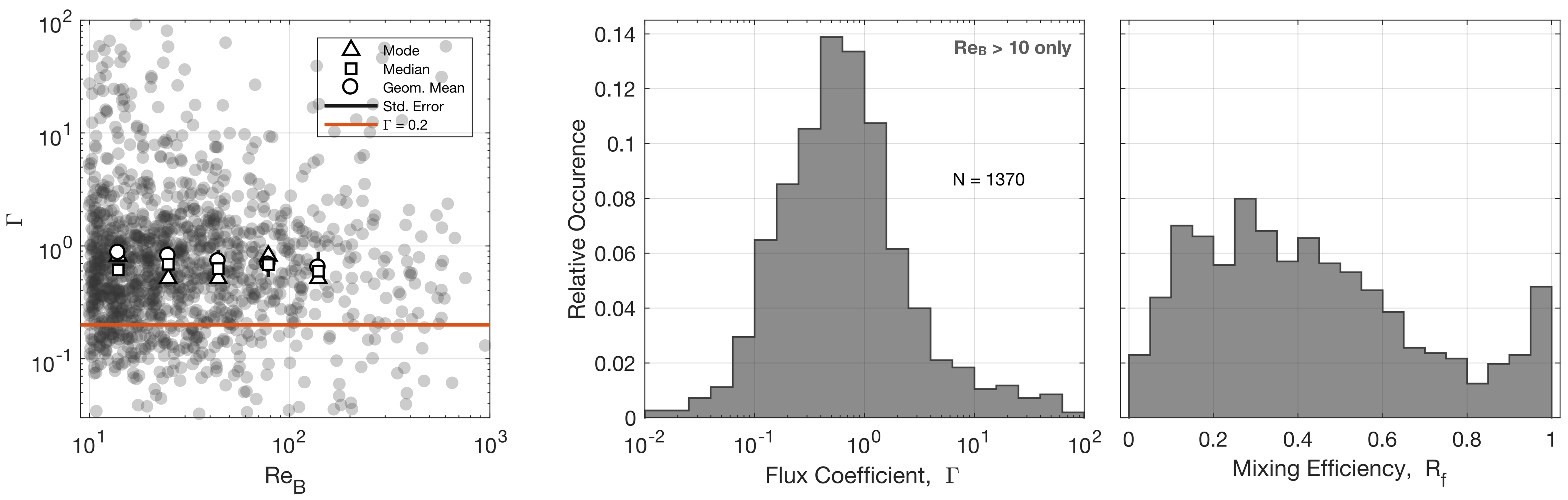
Left — Temperature diffusivity from the Osborn-Cox model, scaled by molecular diffusivity (see Winters & D'Asaro, 1996), as a function of Re_B. Observations converge with the Osborn model (red line) as Re_B→100 but diverge at smaller Re_B. Note at Re_B<10 (left of the yellow line), where it is often assumed that K_T=0, there remains significant turbulent enhancement:

Re_B	Median Diffusivity
0.05	4.6 κ_T
0.1	6.0 κ_T
0.5	12 κ_T
1.0	16 κ_T
5.0	36 κ_T
10	58 κ_T

Right — Ratio of the observed temperature diffusivity K_T to the predicted density diffusivity K_ρ from the Osborn model. The divergence from unity at low buoyancy Reynolds number is systematic and significant; at Re_B=10^{-2}, K_T and K_ρ differ by a factor of 100; at Re_B>10 they agree within a factor of 2. Note K_T observations contain uncertainty from assuming isotropy. Dissipation rate ε is estimated via Batchelor spectra fitting.



Below — Estimates of the flux coefficient Γ and the mixing efficiency R_f, inferred by assuming K_T= K_ρ. Note the calculation is only meaningful when turbulent fluxes dominate molecular ones—we arbitrarily set a cutoff of Re_B>10 for this criterion. We find Γ~0.75 over the range Re_B = 10—200; there is large variability but little trend over this Re_B range. The most common flux coefficient is Γ = 0.5 with IQR = 0.27—1.4; the most common mixing efficiency is R_f = 0.3 with IQR = 0.22—0.58.



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