On forward-backward dispersion in anisotropic turbulence

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We are interested in the dispersion of groups of particles in turbulence, which has been thoroughly studied in the case of homogeneous isotropic turbulence (HIT)[1] or in rotating flows (ROT, Coriolis frequency, f)[2]. We are considering here flows with both rotation and stable stratification (STRAT, Brunt-Väisälä frequency, N). For its oceanographic relevance[3], we chose the ratio $N/f = 5$. In such flows, a transition from eddy-dominated ($R_{\rm IB} > 1$) to wave-dominated ($R_{\rm IB} < 1$) flows was observed[4] when decreasing the Reynolds-Buoyancy number, defined as $R_{\rm IB} = \langle\omega^2\rangle/N^2$.
We analyze the dispersion of pairs of particles forward and backwards in time and compare their dispersion statistics with theoretical predictions of the energy budget generalizing the Kármán–Howarth-Monin equation[5]. Starting with pairs of particles with a given initial separation $||\mathbf{X}_2(0) - \mathbf{X}_1(0)|| = R_0$, we determine the variance of the change of separation, $\langle\delta R^2(t)\rangle = \langle(\mathbf{R}(t) - \mathbf{R}_0)^2\rangle$. The time antisymmetric part, $\langle\delta R^2(-t) - \delta R^2(t)\rangle \approx -2\langle\delta_{\mathbf{R_0}}\mathbf{A}(0)\cdot\delta_{\mathbf{R_0}}\mathbf{U}(0)\rangle t^3 = -2\left(-2\varepsilon_\nu + N\langle\delta_{\mathbf{R_0}}\theta(0)\delta_{\mathbf{R_0}}U_z(0)\rangle\right)$, where $\delta_{\mathbf{R_0}}\mathbf{A}(0)$,$\delta_{\mathbf{R_0}}\mathbf{U}(0)$,$\delta_{\mathbf{R_0}}\theta(0)$,$\delta_{\mathbf{R_0}}U_z(0)$ are the initial values of the pairs relative acceleration, velocity, buoyancy and vertical velocity. This Lagrangian generalization of the 4/5-law includes an energy exchange between kinetic and potential energy. Fig.1 reveals that, despite the exchange term, the time anti-symmetric part reaches a plateau, essentially independent of the scale R_0, down to $R_{IB} \sim 1$ (wave dominated regime). We are exploring the implications of this observation.

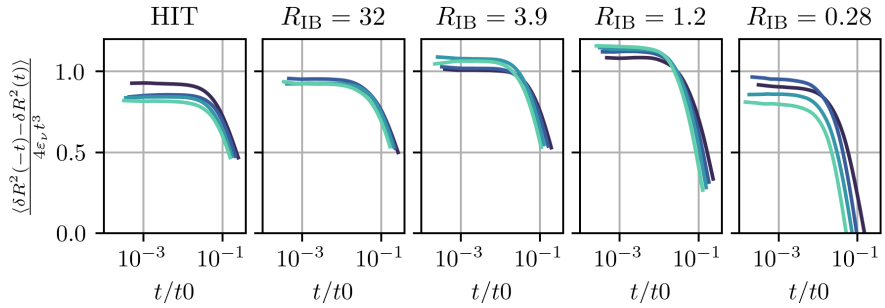

Figure 1: The time antisymmetric part of $\langle\delta R^2(t)\rangle$ compensated by $4\varepsilon_\nu t^3$ for HIT and 4 different ROTSTRAT with decreasing $R_{\rm IB}$. Colors indicate the initial separation of the pairs ranging form 40η (dark blue) to 70η (light green).

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[1]F. Toschi et al. *Ann.Rev.Fluid Mech.* **41**, 1 (2009)
[2]J. Polanco et al., *Phys. Rev. Fluids* **8**, 034602 (2023)
[3]A. C. N. Garabato et al., *Science* **303**, 5655 (2004)
[4]D. Buaria et al., *Phys. Rev. Fluids* **5**, 064801 (2020)
[5]A. Sozza et al., *Physics of Fluids* **27**, 035112 (2015)