Relative dispersion of tracers in turbulent flow: modeling and observations

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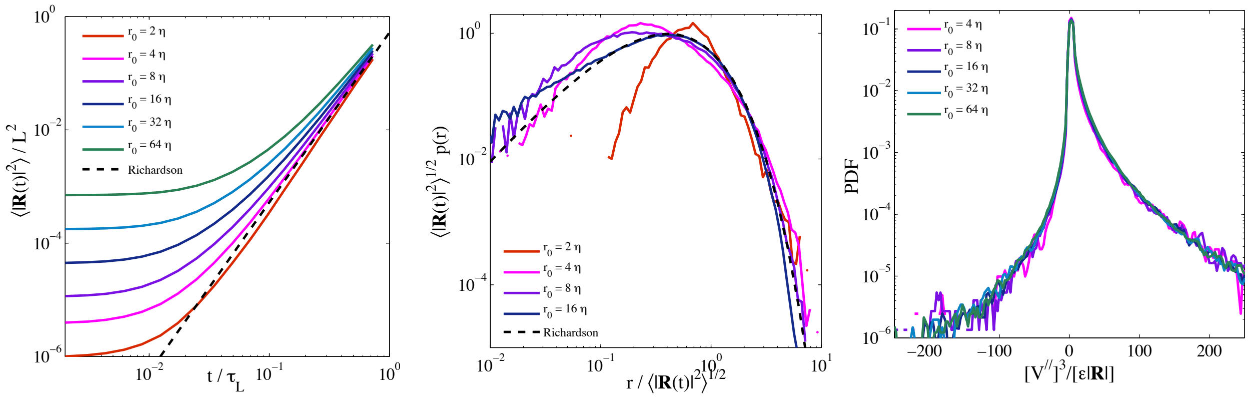
Taylor's large-time diffusive behavior of tracers advected by a turbulent flow is commonly used in applications, as for instance in air quality control. Effective mixing properties are modelled in terms of an eddy diffusivity, which is used to assess possible health hazards due to a long exposure downstream a pollutant source. However this approach fails when interested in the likeliness of finding a local concentration exceeding a high threshold: local fluctuations cannot be determined from the average concentration but relate to its higher-order moments. Second-order statistics, such as the spatial correlations of a passive scalar, are related to the relative motion of tracers (see, e.g., Monin and Yaglom 1971). The problem can be formulated as understanding the time evolution of the separation $\vec{R}(t) = \vec{X}_1(t) - \vec{X}_2(t)$ between two Lagrangian trajectories that are initially at $|\vec{R}(0)| = r_0$. In turbulence, after an initial ballistic regime up to a time t_0 (related to the turnover time associated to the initial separation r_0), the distance $|\vec{R}|$ follows Richardson's superdiffusive law $\langle|\vec{R}(t)|^2\rangle \sim \varepsilon t^3$, where ε is the mean rate of kinetic energy dissipation (see Fig. 1a). The long-term behavior is thus becoming independent of the initial separation r_0, whence the designation of *explosive* pair separation.



(a) (b) (c)

Figure 1: Data from a numerical simulation at $R_\lambda \approx 730$. (a) Evolution of the mean squared displacement $\langle|\vec{R}(t)|^2\rangle$ for various r_0. (b) Rescaled PDF of the separation $r = |\vec{R}(t)|$ at $t = 5t_0$ and various r_0. (c) PDF of the local transfer rate $[V^{\parallel}(t)]^3/|\vec{R}(t)|$ with $V^{\parallel} = \mathrm{d}|\vec{R}|/\mathrm{d}t$ for various r_0 and at $t = 20\tau_\eta$.

The goal of this lecture is to present some phenomenological understanding of the mechanisms underlying this explosive law. With this scope, I will partly review the vast literature on models for relative dispersion (in terms of diffusion, Markovian processes, Levy flights) and balance them with observations resulting from high-resolution numerical simulations. A particular attention will be devoted to the scaling behavior of the probability distribution functions (PDF) of the separation that show significant deviations from Richardson's prediction (Fig. 1b) and to the effect of the fluid flow intermittency. I will also discuss recent observations suggesting the statistical stationarity of the local transfer rate $[V^{\parallel}(t)]^3/|\vec{R}(t)|$ where $V^{\parallel}$ designates the longitudinal velocity difference between the tracers (Fig. 1c).

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