PAIR DISPERSION IN ATMOSPHERIC BOUNDARY LAYERS

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Abstract A Large-eddy Simulation study has been performed of a convective Atmospheric Boundary Layer(ABL), seeded with tracer particles emitted by a line source. By introducing a sub-grid model for small scale Lagrangian dynamics, single diffusion and pair dispersion can be studied in the inhomogeneous and anisotropic ABL flow. Results are presented for tracer separation distribution, velocity statistics and for the concentration fluctuations on the particle deposition.

Dispersion studies in Atmospheric Convective Boundary Layers are relevant for fundamental and applied physics. Indeed, a key problem in the analysis of turbulent diffusion is the determination of the space-time statistical properties of a concentration of a pollutant or a gas released in a turbulent flow at some previous time or by a continuous source. In particular, when dealing with hazardous gas releases, it is crucial to assess not only mean concentration values but also the probability of extreme deviations from the average. In this problem, the main question can be simply stated: given a pair of particles released at time t_0 at a small separation R_0, what is the form of the asymptotic probability, $P(R,t)$, to find them at a distance $R \gg R_0$ at a later time $t \gg t_0$? Very recently, there has been a renewed interest in studying relative dispersion of pairs of marked particles in turbulent flows [1, 2], a topic that was pionereed by L.F. Richardson [3]. It appears that Richardson's diffusive model is appropriate to describe pair separations of the order of the mean ones $R_{rms}(t) = \langle R(t)^2 \rangle^{1/2}$, while it fails in assessing the probability of pairs separating very slowly or very fast.

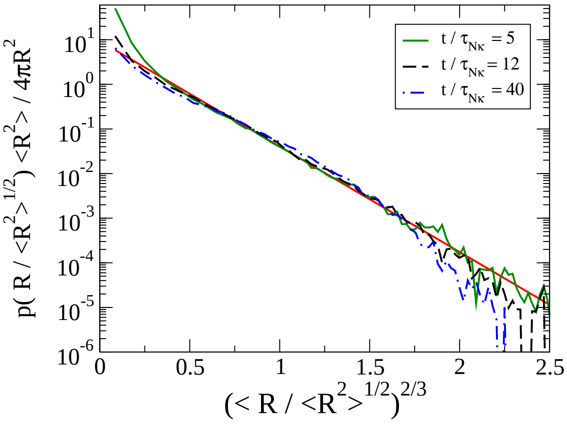

Figure 1. Lin-log plot of probability density function $P(R,t)$ at different times after release (t=0). The red continuous curve is Richardson prediction $P_{Rich}(R,t)$. The scale τ_{N_K} is the fastest time scale of the subgrid-scale Lagrangian model [5]. The ratio of τ_{N_K} with the ABL large-scale eddy-turnover-time τ_* is $\tau_*/\tau_{N_K} \simeq 45$.

Richardson diffusive model is based on some crucial assumptions (the velocity field has a Gaussian statistics, and is statistically homogeneous, isotropic and δ-correlated in time) that are not verified in laboratory turbulent flows (because of multiscale correlations, intermittency, and Reynolds effects), or in ABL flows (which are additionally characterised by the vertical inhomogeneity, and strong anisotropies).

To study in detail particle pair separation in environmental flows, we have performed a series of Large-eddy Simulations of convective ABL flows, seeded with thousands of tracer particles. The incompressible Navier-Stokes equations, with

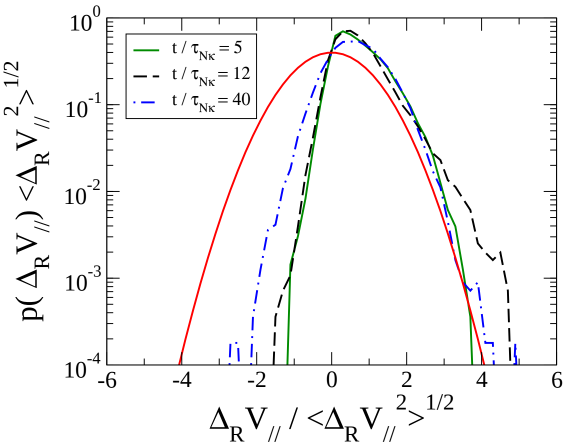

Figure 2. Lin-log plot of probability density function of the longitudinal velocity increments of pairs of particles at distance R, $P(\Delta_R V_{\|}, t)$. A gaussian distribution is also plotted for comparison.

Boussinesq approximation, for the velocity field, and the advection-diffusion equation for the potential temperature are integrated. Closures of turbulent fluctuations at non-resolved scales are obtained by implementing a dynamic subgrid-scale model [4]. To describe space-time small scale evolution of tracer particles, we also implemented a sub-grid scale Lagrangian model which correctly reproduces the correlated motion of bunches of nearby particles [5]. Note that most of the previous studies of dispersion in atmospheric convective boundary layers are limited to single point statistics [6, 7].

In Fig. 1, we present the probability density function (PDF) of pair separation measured in the mixed region of the convective ABL, at different times. The curves are plotted in rescaled variables, such that Richardson PDF $P_{Rich}(R,t)$

$$P_{Rich}(R,t) \propto \frac{R^2}{\langle R^2 \rangle^{3/2}} \; exp\left(- \left[\frac{AR^2}{\langle R^2 \rangle^{1/2}} \right]^{2/3} \right)$$

appears as a straight line: note that the time dependency is absorbed in the term $\langle R^2(t) \rangle$.

In Fig. 2, we plot the PDF of longitudinal velocity increments measured along pair trajectories: note that the velocity increment PDF is positively skewed, reflecting the fact that on average tracers separation always increases in a turbulent flow.

References

[1] R. Scatamacchia, L. Biferale, and F. Toschi. Extreme events in the dispersion of two neighboring particles under the influence of fluid turbulence. *Phys. Rev. Lett.* **109**: 144501, 2012.

[2] R. Bitane, H. Homann, and J. Bec. Geometry and violent events in turbulent pair dispersion. e-arXiv: http://arxiv.org/abs/1209.2296.

[3] L. F. Richardson. Atmospheric diffusion shown on a distance-neighbour graph. *Proc. R. Soc. London*, Ser. A **110**: 709, 1926.

[4] A. S. Lanotte and I. Mazzitelli. Scalar turbulence in convective boundary layers with different entrainment fluxes. *J. Atmos. Sci.* **70** (1): 248-265, 2013.

[5] I. M. Mazzitelli, A.S. Lanotte, and F. Toschi, in preparation.

[6] S.-W. Kim, C.-H. Moeng, J. C. Weil, and M. C. Barth. Lagrangian Particle Dispersion Modeling of the Fumigation Process Using Large-Eddy Simulation. *J. Atmos. Sci.* **62**: 1932-1946, 2004.

[7] A, Dosio and J. Vila'-Guerau De Arellano. Statistics of Absolute and Relative Dispersion in the Atmospheric Convective Boundary Layer: A Large-Eddy Simulation Study. *J. Atmos. Sci.* **63**: 1253-1272, 2006.