NON-RICHARDSON TURBULENT PAIR DIFFUSION REGIMES FOR FLUID AND INERTIAL PARTICLES

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A re-appraisal of the Richardson's dataset [1] shows clear non-local scaling in the fluid particle pair diffusion coefficient, $K(l) \sim l^{1.564}$, which is different to Richardson's originally assumed *4/3* locality scaling law. A new local-non-local theory for turbulent pair diffusion [2] shows that pair diffusion is governed by both local and non-local diffusional processes inside the inertial subrange. For generalized energy spectra, $E(k) \sim k^{-p}$ for $1 < p \leq 3$, the new theory predicts *two* non-Richardson regimes depending on the size of the inertial subrange: first, for asymptotically infinite inertial subrange we obtain, $K(l) \sim l^{\gamma}$, with $\gamma(p)$ intermediate between the purely local and the purely non-local scalings, $(1+p)/2 \leq \gamma(p) \leq 2$; and second, for short inertial subranges, quasi-local scaling laws are obtained, $K(l) \sim l^{(1+p)/2}$. The theory is investigated numerically [3] using Kinematic Simulations [4,5,6], and all the predictions of the theory are observed, most importantly the existence of the two non-Richardson regimes are confirmed. For intermittent turbulence spectra, $E(k) \sim k^{-1.72}$, KS yields, $K(l) \sim l^{1.556}$, in good agreement with the revised 1926 dataset. The concept of local and non-local diffusional processes has been extended to a theory of inertial particle pair diffusion in the Stokes drag limit [7,8] in which the inertial diffusion coefficient $K(l; St, R_k)$ is a two-parameter family of regimes with the Stokes number St and the size of the inertial subrange R_k as the governing parameters. For all Stokes numbers and for short times we observe ballistic motion due to the persistence of the particle momentum. At longer times the energies in the larger turbulent scales begin to dominate and the pair diffusion approaches the fluid particle pair diffusion provided that the inertial subrange is big enough, and the Stokes number is small enough. For very large Stokes numbers, the ballistic regime persists through the entire inertial subrange. All predictions of this theory have been confirmed using KS [8]. These results lend support to the physical picture proposed in the new theories that turbulent diffusion in the inertial subrange is governed by both local and non-local diffusion transport processes. A corollary of these works is that KS has proved to be a remarkably accurate method for modeling pair diffusion scaling laws.

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References

[1] Richardson L. F. Atmospheric diffusion shown on a distance-neighbour graph. *Proc. Roy. Soc. Lond. A* 100, 709-737 (1926).
[2] Malik, N. A., Turbulent Particle Pair Diffusion: A Theory Based on Local and Non-local Diffusional Processes. *PLoS ONE 2018a, (Submitted).*
[3] Malik, N. A., Turbulent Particle Pair Diffusion: Numerical Simulations. *PLoS ONE 2018b, (Submitted).*
[4] Kraichnan, R. H. *Phys. Fluids* 13, 22-31, 1970;
[5] Fung J. C. H., Hunt J. C. R., Malik N. A. & Perkins R. J. Kinematic simulation of homogeneous turbulence by unsteady random Fourier modes. *J. Fluid Mech.* **236**, 281 (1992).
[6] Malik, N. A. Residual sweeping errors in turbulent particle pair diffusion in a Lagrangian diffusion model. *PLoS ONE 12(12): e0189917 (2017).*
[7] Malik N. A. Ninety years in the hunt for turbulent pair diffusion laws. IMA Conf. Turbulence, Waves and Mixing. 6-8 July, Cambridge (2016).
[8] Syed M. Usama & Malik, N. A. Turbulent Inertial Particle Pair Diffusion. *In preparation (2018).*