Diffusion scaling analysis based on renewal theory: an application to turbulent intermittency

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A turbulent fluid flow is characterized by bursting and intermittent behavior [1]. This is associated with the complex dynamics of turbulent energy production and dissipation, which can be described in terms of coherent motions (e.g., eddies, vortices, filaments, ...). Coherent motions are metastable flow structures emerging from the noisy background as a signature of the self-organization determined by the fluid dynamics. These flow structures are generated at random times and remain stable for relatively long life-times. After this life-time, they become suddenly unstable and a rapid decay occurs. The generation and annihilation episods occur on very short times with respect to the long life-time of the coherent, self-organized flow structures, so that they can be treated as quasi-instantaneous events. The emergence and evolution of intermittent structures are associated with a power-law decay of correlation functions and of Inter-Event Time (IET) distribution. The power exponent of the IET distribution can defined to be a measure of the system's complexity. Self-organized criticality and non-extensive thermodynamics are the most common theoretical frameworks used to describe turbulence. However, in recent times, renewal theory [2], assuming that the events are statistically independent, was proposed to analyse atmospheric time series [3]. The authors estimated the sistem's complexity by directly evaluating the power-law decay of the IET distribution, which is a crucial parameter under the renewal assumption. The IET distribution was also used for a statistical analysis being able to check the renewal assumption. However, the results of this analysis and the estimation of the system's complexity are limited by the presence of added noise in the time series, as it affects the shape of IET distribution. In the present work we introduce a novel statistical analysis that overcomes this limitation and we show an application of the analysis to turbulence data in the atmospheric boundary layer. Firstly, the experimental time signals are processed to extract sequences of events associated with the birth and death of coherent intermittent structures. Then, we perform the proposed analysis, which is based on the estimation of the diffusion scaling of random walks derived from the experimental event sequences [4,5]. This analysis allows to estimate indirectly the system's complexity, the renewal assumption and the level of noise in the time series.

[1] U. Frisch, Turbulence: The legacy of A.N. Kolmogorov, (Cambridge University Press, 1995).
[2] D.R. Cox, Renewal Theory, (Methuen, London, 1962).
[3] P. Paradisi, et al., Eur. Phys. J. 174, 207 (2009).
[4] P. Allegrini, et al., Phys. Rev. E 80, 061914 (2009).
[5] P. Allegrini, et al., Phys. Rev. E 82, 015103(R) (2010).