Fractal reconstruction of sub-grid scales for particle dispersion in large eddy simulation

Emmanuel O. Akinlabi[1], Marta Wacławczyk[1], Szymon P. Malinowski[1], Juan-Pedro Mellado[2]

[1]Institute of Geophysics, Faculty of Physics, University of Warsaw, Warsaw, Poland
[2]Max-Planck Institute for Meterology, Hamburg, Germany

ABSTRACT

Particle dispersion in turbulent flows have attracted the attention of researchers in recent times due to its wide range of application such as pollutant dispersion, spray dynamics, cloud dynamics etc. Direct numerical simulation (DNS) is the most detailed research tool, used to accurately predict particle trajectories in turbulent flows. For high-Reynolds number flow, this tool requires unrealistic computational resources and as a compromise, Large eddy simulation (LES) is used. LES provides a better representation of large-scale features of the flow while sub-grid (unresolved) scales are modelled. Sub-grid scale model errors can lead to the progressive divergence of particle trajectories when compared with those obtained in experiment or DNS [2]. As a result, particle statistics are either over- or under-estimated [1, 4].

The present work addresses the reconstruction of sub-grid scales in large eddy simulation (LES) of turbulent dispersed flows. We focus on fractal sub-grid model, which is based on the fractality assumption of turbulent velocity field. The fractal model reconstructs sub-grid velocity field from known filtered values on LES grid, by means of fractal interpolation, proposed by Scotti and Meneveau [6]. The characteristics of the reconstructed signal depend on the (free) stretching parameter d, which is related to the fractal dimension of the signal. In [6], the stretching parameter was assumed to be constant in space and time and are obtained from experimental data of homogeneous and isotropic turbulence. However, turbulence at moderate or high-Reynolds' number possesses intermittency at small scales, which lead to strong variability in its local stretching parameter. To account for the stretching parameter variability, we calculate the probability distribution function of the local stretching parameter from DNS data of stratocumulus top boundary layer (STBL) [5] using an algorithm proposed by Mazel and Hayes [3]. We observe self-similarity in the PDFs of d when the velocity fields are filtered to wave-numbers within the inertial range (see figure 1). By randomly selecting d from its self-similar PDF, we perform a 1D a priori test and compare statistics of the constructed velocity increments with statistics of DNS velocity increments (see figure 2). This idea was applied to Physics of stratocumulus top (POST) airborne data and 3-D LES velocity fields. We observed that the constructed sub-grid scale velocity fields with the random values of d are able to reproduce most of the sub-grid scales and give smaller error in mass conservation when compared to the use of constant values of d.

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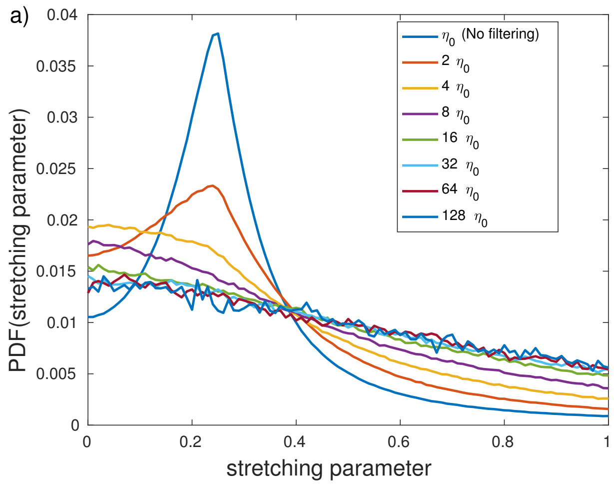

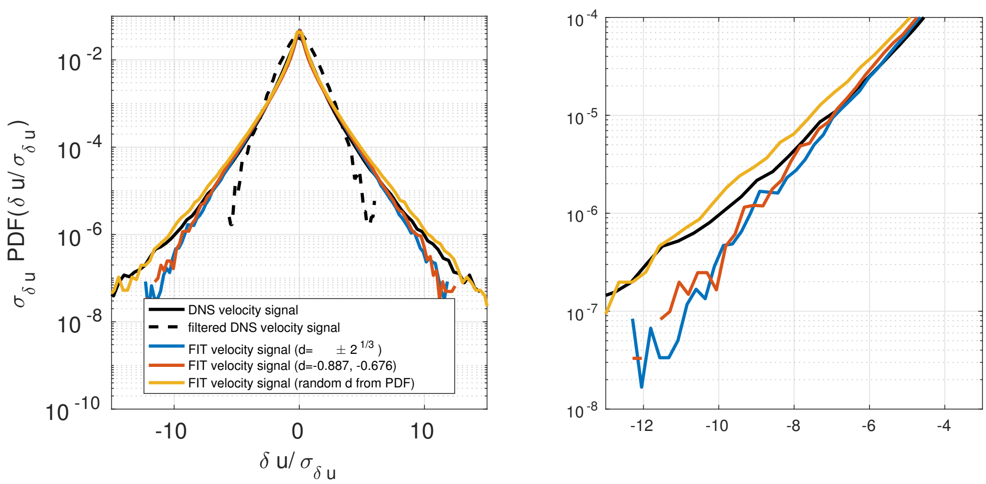

Figure 2: PDFs of DNS, filtered and FIT velocity increments (δu) signal for u velocity component at $|\mathbf{r}| = 2\eta_0$ with constant stretching parameter $d = \pm 2^{-1/3}$, $d = -0.887, -0.676$ and random stretching parameters from DNS calculated PDF