Complex network characterization of Lagrangian mixing in a turbulent channel flow

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Abstract

Turbulent mixing plays a fundamental role in several natural phenomena and practical applications, due to its effectiveness to enhance transport [1, 2]. Here we propose a complex network-based approach to study turbulent mixing from a Lagrangian viewpoint [3]. Among different research areas in which network science has been exploited, turbulence represents an emerging field of application, so that complex networks offer a novel perspective on the turbulence dynamics. In our work, a direct numerical simulation (DNS) of a fully-developed turbulent channel flow was employed at a (frictional) Reynolds number $Re_\tau = Hu_\tau/\nu = 950$, where u_τ is the friction velocity, H is the half-channel height and ν is the kinematic viscosity [4]. A set of 100×100 fluid particles was uniformly released at the initial time in the plane (y^+, z^+) at $x^+ = 0$ (e.g., see figure 1(a)), where the streamwise, wall-normal and spanwise coordinates are (x^+, y^+, z^+), respectively. Particles were grouped into $N_y = 100$ wall-normal levels, and particle positions were tracked for a total time $T = 15200\nu/u_\tau^2$. In order to build the network, each node was associated with a wall-normal level, while connections between particle pairs were established based on their spatial proximity (see figure 1). Specifically, two particles are connected if their Euclidean distance (at each time) is sufficiently small; the proximity boundary is represented by an ellipsoid with semi-axis values that are proportional to the average pairwise distance between all particles (see figure 1(b)). In this way, since the pairwise distance between particles depends on time, we obtain a time-varying network made up of $N_t = T/\Delta t = 3200$ graphs. Specifically, each node in the graphs comprises a set of $N_z = 100$ particles, and each link is weighted to quantify the interaction strength between particle pairs in each node.

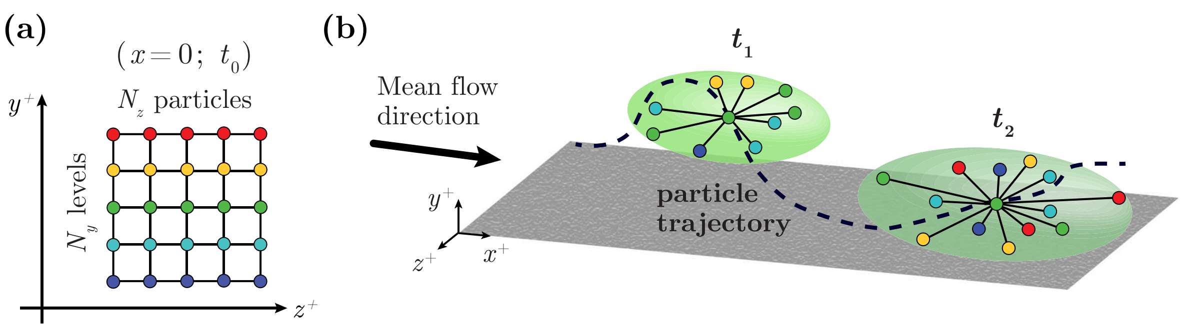

Figure 1: Sketch of the set-up, in which particles and connections are depicted as coloured spheres and black lines, respectively [3]. (a) Particles initially released from a uniformly spaced grid at $x^+ = 0$; (b) particle connections at different times, where the ellipsoids represent the proximity boundaries of each particle.

The structure of the resulting time-varying network captures non-trivial insights into the effects of turbulence on particle dynamics, as it emerges from the different patterns in the weight matrices, $W_{i,j}$ (see figure 2). More in detail, network metrics are able to reveal the extent to which both the mean flow advection and wall-normal turbulent mixing affect the particle dispersion. By doing so, we extract two time scales corresponding to the dominant advection regime, i.e. $t^+ < 400$ (see figure 2(b-c)), and the asymptotic Taylor's regime of dominant vertical mixing, i.e. $t^+ > 5000$ (see figure 2(e-f)) [3]. Moreover, through the network analysis it is possible to characterize the effect of the mean shear on particle dispersion, as well as the appearance of extreme events (i.e., mixing between particles initially far in space) [3]. Based on present findings, Lagrangian-based networks can pave the way for a systematic network-based investigation of turbulent mixing, thus extending the level of information of classical statistics.

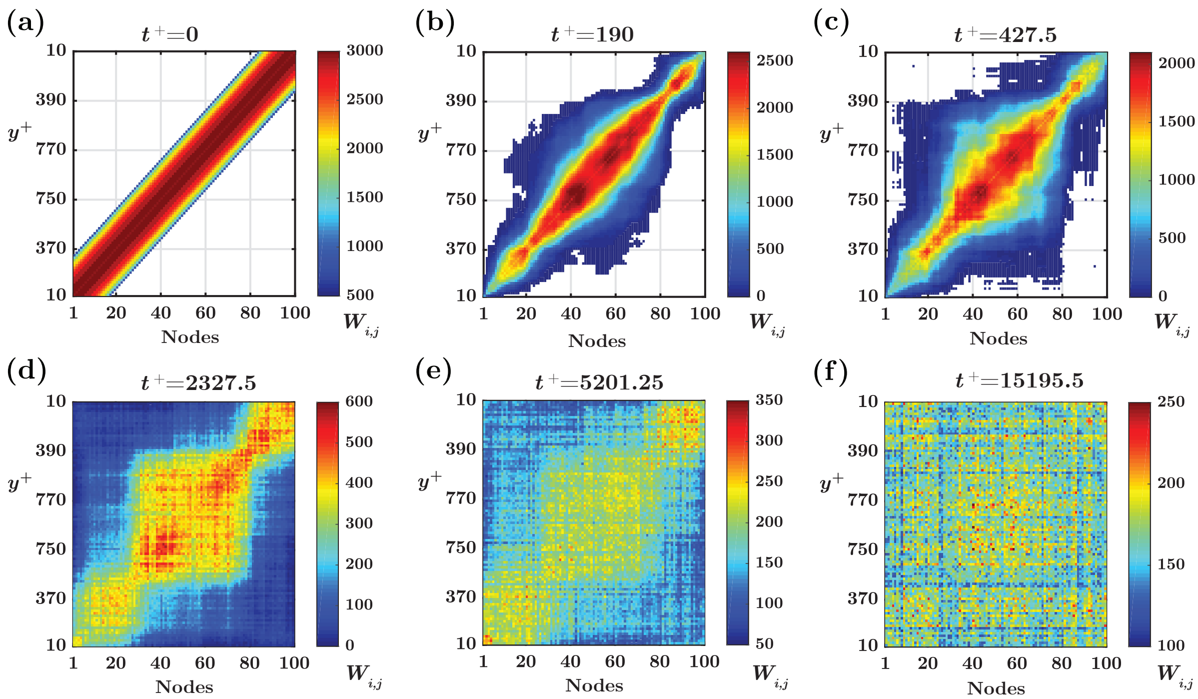

Figure 2: Representation of the time-varying network as weight matrices, $W_{i,j}$, for node pairs (i, j). Colorbars indicate the weight intensity of each link in the networks [3].

References

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