NETWORK-BASED CHARACTERIZATION OF PASSIVE-SCALAR PLUME DYNAMICS IN A TURBULENT BOUNDARY LAYER

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The investigation of the interplay between the passive-scalar dynamics and the velocity field in a turbulent boundary layer (TBL) is essential to understand and model the transport of contaminants in atmospheric TBLs. Specifically, the characterization of concentration peaks is crucial to identify the possibility to exceed concentration limits [1]. In this work, we take advantage of the recent developments in network science to study the vertical transport of a passive-scalar in a TBL. Experimental measurements of velocity and passive-scalar are performed in a wind tunnel which generates a TBL with a free-stream velocity $u_\infty = 4.94$ m/s and a thickness $\delta = 314$ mm [5]. A mixture of air-ethane was released from an L-shaped source of diameter D, located at a distance $h_s/\delta \approx 0.24$ from the wall (see Fig.1a). Time-series of vertical passive-scalar flux, $w'c'$, were obtained for two diameter values, $D = \{3, 6\}$ mm, at different streamwise and wall-normal positions, (x, z). Here, w' and c' are the fluctuating components of wall-normal velocity and concentration, respectively. Data were measured over a time interval of 180 s, with sampling frequency equal to 1000 Hz, thus obtaining $N_T = 1.8 \times 10^5$ time-samples. To investigate the time-series of $w'c'$, the visibility algorithm was exploited [4]. The visibility-graph technique is one of the simplest and most employed approaches to map a time-series into a complex network [6]. According to this method, each point of the time-series corresponds to a node of the network, which therefore has N_T nodes. A link between two nodes exists if the straight line connecting the two data points lies above all the other in-between data. To highlight the key mechanisms affecting the plume dynamics – i.e., the meandering of the plume centre of mass and its relative dispersion [2] – we investigated two network metrics: the average peak occurrence, ϕ, and the transitivity, Tr. These metrics are related to the occurrence of extreme events and irregularities in the time-series, respectively [3]. In Fig.1b the behaviour of ϕ and Tr is shown as a function of z/δ at two streamwise locations: in the source proximity and far from the source. Relative dispersion along z is well captured by ϕ, which significantly decreases for both D cases towards the far field (see Fig.1b, left panels). The Tr magnitude does not substantially vary from near to far field. However, the ϕ and Tr differences between the two diameters along the source axis denote an important variation of the meandering effect in the near field (see Fig.1b, top panels). The network-based analysis helps characterizing the impact of the source diameter on the passive-scalar plume dynamics in a TBL. Based on the present findings, the near-field meandering is influenced by the source size much more than relative dispersion throughout the domain is.

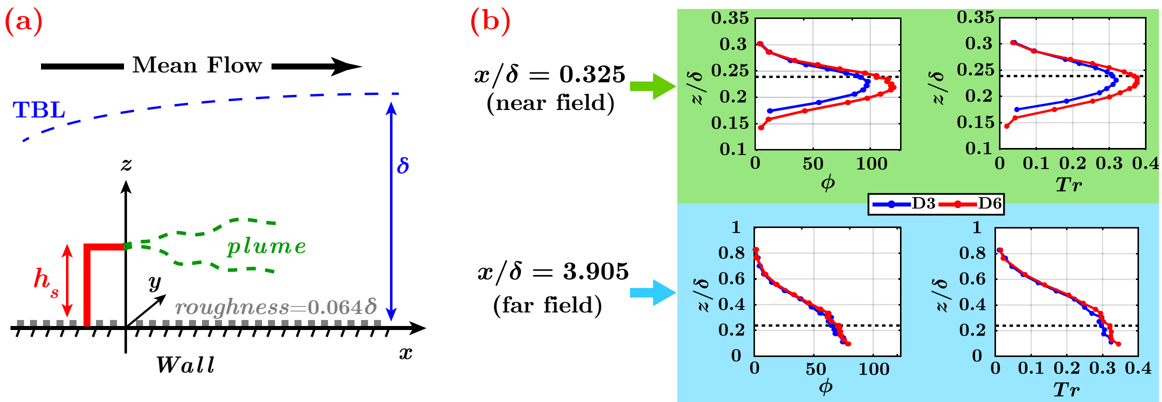

Figure 1. (a) Sketch of the wind tunnel set-up (not drawn to scale). (b) Mean link length, ϕ, and transitivity, Tr, as a function of z/δ, for two source diameters, $D = \{3, 6\}$ mm, and at two streamwise locations, x/δ. Dashed lines indicate the source height, h_s.

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