

CHARACTERIZATION OF TURBULENT CHANNEL FLOWS: FROM TIME-SERIES TO COMPLEX NETWORKS

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Experimental and numerical simulations provide nowadays a great amount of detailed spatio-temporal data, which needs to be properly examined to achieve a better description of the turbulence dynamics. New investigative tools are hence continuously required to handle and properly interpret such *big-data*. In this context, complex network theory — by combining graph theory and statistical physics — recently turned out to be a powerful framework to analyze complex systems, such as turbulent flows [4],[5]. In this work, a DNS of a fully-developed turbulent channel flow [1],[3] is investigated through the natural visibility graph (NVG) method [2]. A subset of the simulation grid domain is firstly selected, acquiring all the available temporal data for the velocity field, (u, v, w) , and for the kinetic energy, K . The time-series of each selected grid-point is then mapped into a network by means of the NVG method. In particular, two data values constitute a pair of linked nodes of the network if the straight line connecting the two data points lies above the other in-between data. The *degree centrality*, k , quantifying the visibility of nodes, is the first metric studied. The transitivity, Tr , and the newly introduced *mean link-length*, d_{1n} , are then evaluated as indicators of the inter-visibility and mean temporal distance among nodes, respectively. The metrics are averaged along the directions of homogeneity of the flow (i.e., x and z), thus they only depend on the wall-normal coordinate, y^+ (see Fig. 1a). The visibility-based networks inherit the temporal structure of the corresponding time-series, as we observe the trend of the metrics is closely related to the flow properties along y^+ . In this way, different temporal features of the time-series are mapped in the networks and the metric trends (Fig. 1a) allow one to shed light on how the temporal structure of the series changes moving along y^+ (see Fig. 1b). Although intrinsically simple to be implemented, the visibility graph-based approach then offers a promising support to the classical methods for accurate time-series analyses of inhomogeneous turbulent flows.

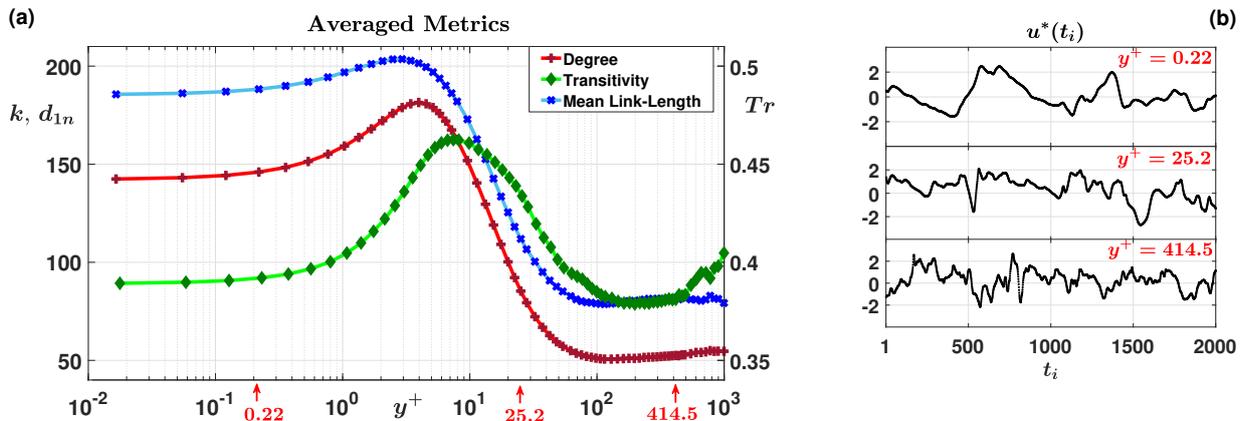


Figure 1. (a) Averaged metrics (k, Tr, d_{1n}) as function of the wall-normal coordinate, y^+ . The metrics are obtained from networks built on time-series extracted from the streamwise velocity component, $u(t)$. (b) First 2000 time instants extracted from time-series of the streamwise velocity component at three representative y^+ stations ($y^+ = \{0.22, 25.2, 414.5\}$) and at fixed (x, z) coordinates. Normalization is taken as $u^* = (u - \mu)/\sigma$, where μ and σ are the mean and standard deviation values of $u(t_i)$, respectively.

References

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