Characterization of turbulent channel flows: from time-series to complex networks

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.

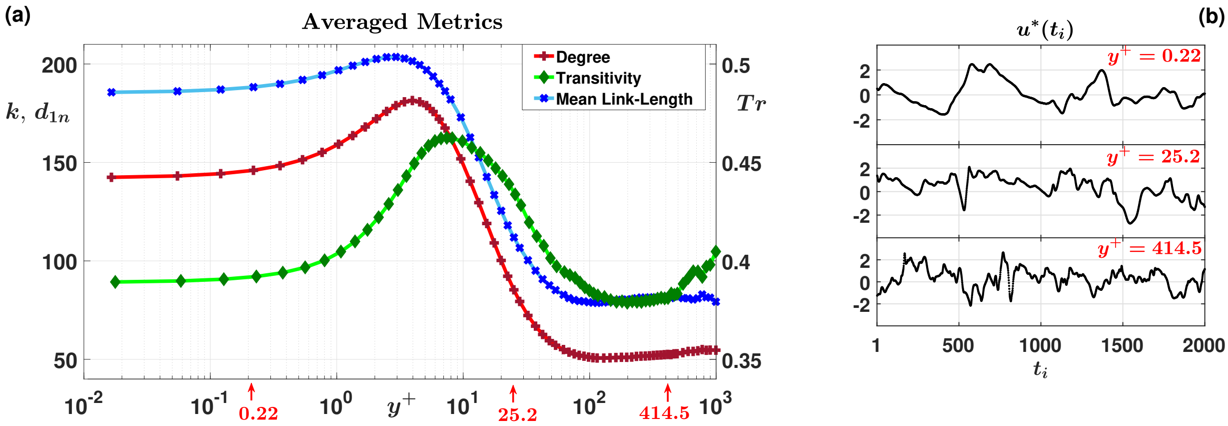

Figure 1. *(a)* Averaged metrics (k, Tr, d_{1n}) as function of the wall-normal coordinate, y^+. The metrics are obtained from networks built on time-series extracted from the streamwise velocity component, $u(t)$. *(b)* First 2000 time instants extracted from time-series of the streamwise velocity component 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

[1] J. Graham et al. A web services accessible database of turbulent channel flow and its use for testing a new integral wall model for LES. *Journal of Turbulence*, **17**(2):181–215, 2016.
[2] L. Lacasa et al. From time series to complex networks: The visibility graph. *Proceedings of the National Academy of Sciences*, **105**(13):4972–4975, 2008.
[3] Yi Li et al. A public turbulence database cluster and applications to study lagrangian evolution of velocity increments in turbulence. *Journal of Turbulence*, (9):N31, 2008.
[4] S. Scarsoglio, G. Iacobello, and L. Ridolfi. Complex networks unveiling spatial patterns in turbulence. *International Journal of Bifurcation and Chaos*, **26**(13):1650223, 2016.
[5] K. Taira et al. Network structure of two-dimensional decaying isotropic turbulence. *Journal of Fluid Mechanics*, **795**:R2, 2016.