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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, \(T_r\), 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 \((k,T_r,d_{1n})\) 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 \(\mu\) and \(\sigma\) are the mean and standard deviation values of \(u(t_i)\), respectively.

**References**


