Spatial Network Investigation of Wall Turbulence

Introduction & Objectives

- Recent increasing interest in complex network applications to physical and engineering problems;
- Most network analyses related to fluid flows have been focused on topics including two-phase flows [1] and geophysical flows [2];
- We propose a filtering information [3] correlation-based spatial network investigation of a turbulent channel flow;
- The aim is to provide a spatial characterization of the flow dynamics [4] by introducing an alternative technique to study wall turbulence.

Database & Methods

- Data: from a direct numerical simulation of a fully developed turbulent channel flow [5];
- Velocity Field: \((u, v, w) \rightarrow u_v = U_C(y) \rightarrow R_y = \frac{\langle u'_v x'_v \rangle}{\sigma_x \sigma_v} \) correlation coefficients;
- Spatial Network: Nodes \(\rightarrow\) Selected grid points \(\rightarrow n \approx 10^6\);
- Network Building: \(A_{ij} = 1\) if \(|R_{ij}| > 0.85 \rightarrow L \approx 10^8\);
- Definitions:
  - Volume Weighted Connectivity [6]: \(VWC(i) = \sum_j w_j V_j \) (Fig. 3);
  - Region, \(R\): set of nodes satisfying a three-dimensional 6-connectivity;
  - \(n\)th cumulative neighborhood: \(V_{W,C} = U_{ij} = V_{ij} R_{ij} \) (Fig. 3).

Results

- In the network there are hubs highly connected to other parts of domain (Fig. 2a): o Such hubs tend to group into elongated clusters of hubs, CoH, both close to the walls and the center (Fig. 3a).
- The neighbors of the \(i\) – \(VWC\) nodes tend to group into short-range \(R_{ij}\) and long-range \(R_j\) regions (Fig. 2c);
- \(i\) – \(VWC\) nodes close to the walls have different topological features than \(N – VWC\) nodes at the center (Fig. 3c);
- Long-range neighbors are not scattered in space but (as the relative CoH) tend to cluster into regions \(R_{ij}\) (Fig. 3f).
- The CoH and the regions of long-range neighbors constitute strongly correlated parts of domain;
- Nodes in the \(R_{ij}\) and \(R_j\) regions have unique correlation sign with the nodes in the corresponding CoH.
- The behavior of \(\Gamma_{ij}\) of nodes with different \(VWC\) and \(y^+\) highlight the kinetic information flows in the domain (Fig. 4);
- The high-correlation network based on the \(u\)-velocity is a framework where the kinematic message flow among nodes.

Discussion & Conclusions

- CoH: Coordinated hubs of interest;
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References

9. Computational resources provided by ‘HPCNED’ (www.hpc.polito.it) and SURFshare Cartesia (www.surf.nl);