Summary

The aim of this Thesis is to propose a novel way to investigate wall-bounded turbulent flows, which relies on complex networks. The combination of fluid dynamics and complex networks theory results in an innovative and strongly multidisciplinary approach, which has been attracting growing interest. Differently from classical statistics, complex networks represent a suitable and powerful tool to capture and study the inter-connections between the elements of a discrete complex system. Therefore, the idea behind this work is to take advantage from the great developments of the recently established network science, to advance the level of information of classical statistics in the spatio-temporal characterization of wall turbulence.

Three main approaches are pursued to analyse turbulent flows in the view of (i) one-point time-series, (ii) Eulerian spatio-temporal fields and (iii) Lagrangian particle trajectories. About the first approach, one-point time-series are mapped in complex networks in which nodes correspond to temporal data, while links are established by means of the visibility algorithm. Here, for the first time the visibility algorithm is used to investigate a (numerically simulated) turbulent channel flow and a passive scalar plume in an experimental turbulent boundary layer. In both cases, particular efforts are paid to relate network metrics to the temporal structure of the signals. This fundamental issue has often been disregarded, since the meaning of the metrics has usually been interpreted only as a network feature rather than a signal feature. Results show that the visibility-based networks are able to quantify the presence of small fluctuations in the series, as well as the relative intensity of extreme events and their temporal occurrence. This information – usually hidden in classical statistics based on the signal PDF – is crucial, e.g., in the dispersion of contaminants in the atmospheric turbulent boundary layer, which is tackled in this Thesis via an experimental study.

The second approach concerns the Eulerian framework, and complex networks are exploited to explicitly emphasize high-correlation regions in a turbulent channel flow. In this case, nodes correspond to grid points and represent the volume of each cell in the computational domain. In this way, we extend the idea pursued in climate network analysis to weigh nodes on the corresponding surface areas. Links are activated if the two-point correlation of the velocity field is above a suitable

threshold, which is chosen in order to highlight large (positive and negative) correlation values. The main outcome is represented by the appearance of long-range connections – referred to as teleconnections – between distant near-wall locations. Teleconnections are found to be associated to an analogous response of the near-wall velocity field due to large-scale motions. The spatial texture of teleconnections is straightforwardly highlighted by the network links, which – differently to the classical average correlation – is able to retain the spatial information of high correlation coefficients.

Finally, in the third approach, fluid particle trajectories are exploited to study turbulent mixing in a channel flow by means of a time-varying weighted network. In this framework, nodes correspond to groups of particles and a spatial proximity criterion is employed to establish (weighted) links in the network, whose structure evolves in time. By doing so, we are able to clearly identify characteristic regimes of particle dispersion, as well as the interplay between advection and mixing on particle dynamics. The Lagrangian time-varying network approach, therefore, is able to capture the transient effects of the particle dynamics, differently from other works in which the full trajectories are exploited to activate links (thus loosing transient mechanisms).

For each of the three perspectives, complex networks reveal to be an effective tool to capture turbulence features that would be complicated to highlight through other techniques. More in details, complex networks are fully able: to inherit higher-order information of time-series (by highlighting the occurrence and relative intensity of extreme events); preserve the spatial information of correlation in all directions between different (even long-range) spatial locations; and to reveal local and global mixing effects of particle dispersion (thus providing in a unique framework a geometrical representation of particle dynamics over time). Based on present findings, the complex network approach can pave the way for a novel multidisciplinary research area that, beyond the proposed applications, can involve other turbulence configurations as multiphase and thermal or density inhomogeneous flows.