Multiscale analysis of time irreversibility in wall turbulence

G. Iacobello[a], S. Chowdhuri[b], L. Ridolfi[c], L. Rondoni[d], and S. Scarsoglio[e]

Time irreversibility represents a distinctive feature of non-equilibrium systems and has been the subject of many studies, ranging from the original investigations that led to the kinetic theory of gases to, for example, river flows and human heartbeat. Time asymmetry in stationary time-series, in fact, reveals key features of the corresponding dynamical system, like nonlinearity and non-Gaussianity[1]. Among relevant physical systems, turbulent flows have also been investigated under the lens of time irreversibility[2] that is typically associated with energy cascade in the scale-space (i.e., leading to a preferential direction of energy transfer). However, most of the studies of time irreversibility in turbulence have focused on homogeneous isotropic turbulence[3], and backward-forward statistics of tracer trajectories have mainly been explored to look into time asymmetry in wall-bounded turbulence[4]. This work aims to investigate time irreversibility in wall-bounded turbulence from one-point time series instead of Lagrangian trajectories, and connect such feature with the underlying flow structure. The contribution to time irreversibility from different time scales is investigated, together with the effect of increasing wall-normal distance. A measure based on a visibility-graph representation of time series[5] is used to quantify time irreversibility from streamwise (one-point) velocity signals, experimentally measured on a turbulent boundary layer at friction Reynolds number Re_τ=14750. Results show significant variations of time irreversibility values along the wall-normal direction, as well as across different time scales. The analysis, also corroborated through other irreversibility measures (e.g., based on the fluctuation theorem[1]), reveals a connection between higher time irreversibility values and the spatial arrangement of turbulent coherent structures in the flow. In a broader perspective, present findings can shed light on the role of organised flow structures (with different characteristic scales) in the generation of temporal asymmetry in the flow dynamics, at different wall-normal distances.

[a] School of Mechanical Engineering Sciences, University of Surrey, Guildford, GU2 7XH, UK
[b] Indian Institute of Tropical Meteorology, Ministry of Earth Sciences, Pune, 411008, India
[c] Dep. Environmental, Land and Infrastructure Engineering Politecnico di Torino, Turin, 10129 Italy
[d] Dep. Mathematical Sciences, Politecnico di Torino, Turin, 10129, Italy
[e] Dep. Mechanical and Aerospace Engineering, Politecnico di Torino, Turin, 10129, Italy

[1] Porporato et al., *Phys. Rev. Lett.*, **98**(9), 094101 (2007).
[2] Rondoni and Segre, *Nonlinearity*, **12**(6), 1471 (1999).
[3] Jucha et al., *Phys. Rev. Lett.*, **113**(5), 054501 (2014).
[4] Polanco et al., *Int. J. Heat Fluid Flow*, **71**, 231(2018).
[5] Iacobello et al., *Physica A*, **563**, 125476 (2021).