MASSIVE COMPUTATIONAL STUDY OF CAUSAL EVENTS IN TURBULENT CHANNEL FLOW

Kosuke Osawa & Javier Jiménez
School of Aeronautics, Universidad Politécnica de Madrid, 28040 Madrid, Spain.
E-mail: kosawa@torroja.dmt.upm.es

Causally important events are studied in turbulent channel flow by seeing the effect of intervening init. The methodology follows the causal analysis of 2D HIT by Jiménez [1]. The basic idea is to perturb a small part (hereafter "cell") of the flow, and measure how much the development of the flow changes from the original, to know the causal significance of the perturbed cell. This experiment is repeated many times, and common flow features of causally significant or irrelevant cells are elucidated using large data ensembles. In this study, we perform a total of 29520 direct numerical simulations of turbulent open channel flow at $Re_\tau = 609$. The domain size is $l_x \times l_y \times l_z = \pi h \times h \times \pi h$, where x, y and z are the streamwise, wall-normal and spanwise directions, respectively, and h is the channel height. The initial perturbation is to remove the velocity fluctuations in the cell, implemented by overwriting the velocity in the cell with its $x - z$ mean, and imposing continuity after the modification. Cells are cubes of size of $l^+_{cell} = 25, 50, 100$ and 150, where the superscript $+$ denotes wall units. Because the flow is inhomogeneous in y, the central height of the cell, y_{cell}, is also an important parameter, and is varied from $l_{cell}/2$ (attached to the wall) to 300 wall units. Causal significance is either measured by the squared norm of the velocity difference between the perturbed and original flows, $\varepsilon_{\boldsymbol{u}} = ||\boldsymbol{u}_{per} - \boldsymbol{u}_{org}||^2$, or by its relative growth $\varepsilon_{\boldsymbol{u}}(t)/\varepsilon_{\boldsymbol{u}}(0)$.

Causal features change a lot depending on whether the causal significance is measured by the absolute magnitude of the difference, $\varepsilon_{\boldsymbol{u}}$, or by its relative growth. When the magnitude is used, cells with an initially larger perturbation tend to be more causally significant. This result is robust to the evaluation time, to l_{cell} and to y_{cell}. On the other hand, when the growth is used, the causally significant cells depend on the time and on y_{cell}. At the time, t_{sig}, at which the causal significance of the different cells diverges the most, significant cells tend to be in sweeps, whereas irrelevant ones tend to be in ejections. Figure 1 shows $\varepsilon_{\boldsymbol{u}}$ averaged over $x - z$ for: (a) significant cells, and (b) irrelevant ones. Generally, the perturbation initially spreads both up and down, but only grows substantially after it reaches the wall. As characterized by the peak height of $\varepsilon_{\boldsymbol{u}}$ (bold line), the perturbation of the significant cells move down to the wall faster than the irrelevant ones. This suggests that sweeps tend to be more causally significant than ejections because they carry the perturbation faster to the wall, where it develops due to the higher shear. The time t_{sig} is found to be roughly proportional to y_{cell}, supporting the idea that the perturbation propagation toward the wall decides its causal significance.

Funded by the Caust grant ERC AdG-101018287.

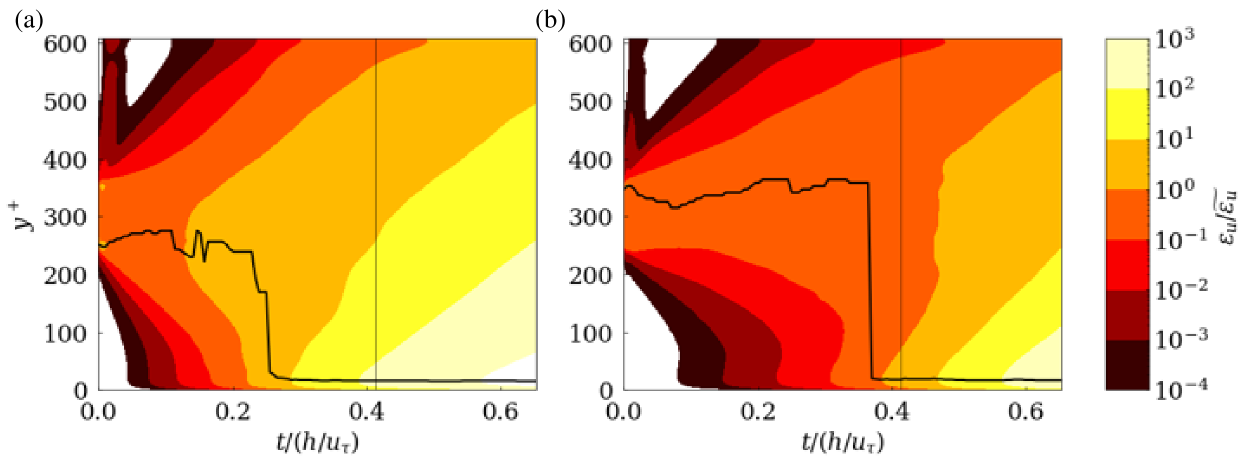

Figure 1. Temporal and wall-normal development of $\varepsilon_{\boldsymbol{u}}$, averaged over $x - z$. (a) Conditioned to causally significant perturbations. (b) Causally irrelevant. Causal significance defined by relative growth, and normalized by the initial $x - y - z$ mean value of all samples. Vertical line: t_{sig}. Bold line: Peak height of $\varepsilon_{\boldsymbol{u}}$. $l^+_{cell} = 100$, $y^+_{cell} = 300$.

References

[1] Jiménez, J, Computers and turbulence. *Europ. J. Mech. B: Fluids* **79**, 1–11 (2019).