CAUSALITY IN SEDIMENTARY TURBULENT CHANNEL FLOWS

Markus Scherer and Markus Uhlmann
Institute for Hydromechanics, Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany.
E-mail: markus.scherer@kit.edu

Recently, direct numerical simulations have provided evidence that the information exchange between the near–wall and the outer region of turbulent channel flows is an asymmetric process, with information being preferentially transported from the outer flow towards the wall [2]. Causalitywise, this observation implies that the flow structures in the outer layer exert a significant influence on the dynamics of their counterparts in the near–wall region [4], whilst the impact of the latter on the outer layer structures seems to be limited. Compared to the canonical case, the causal relations between outer and near–wall dynamics in hydraulic free–surface flows over mobile sediment beds are less well understood. In this talk, we discuss as an example for an open causality problem in hydraulics the development of streamwise–aligned sediment ridges on an initially flat mobile sediment bed sheared by a turbulent open channel flow (cf. figure 1). While these sediment ridges are well–known to closely interact with secondary currents of Prandtl's second kind, it remains unclear whether a lateral bed variation causes the formation of secondary flow patterns in a 'bottom–up mechanism' or whether, *vice versa*, a spanwise variation of the turbulent flow is responsible for the evolution of the characteristic bedforms implying a 'top–down mechanism' [5].

By means of interface–resolved direct numerical simulations incorporating an immersed boundary technique and a discrete element model [7, 3], we show that the formation of sediment ridges is controlled by the outer large–scale velocity streaks and associated Reynolds stress–carrying structures in a 'top–down mechanism' that is in line with the concept of causality in canonical single–phase channel flows outlined in [2]. In this context, two–point two–time correlations reveal that the sediment bed evolution follows the dynamics of the large–scale structures in the channel bulk with a delay of several bulk time units, underlining the causal relation between both. The large–scale flow structures induce spanwise–alternating regions of low and high bed shear stress and thus lead to a locally reduced or enhanced erosion activity. The eroded sediment concentrates in a rather thin but intense sediment transport layer above the bed that disrupts the classical buffer–layer processes. The dynamics of the largest–scale structures in the channel bulk, on the other hand, do not significantly differ from those in single–phase smooth–wall open channels, thereby supporting earlier observations over fully–rough bottom walls according to which the outer flow is essentially unaffected by the details of the near–wall dynamics [6, 1].

Funding The current work was supported by the German Research Foundation (DFG) through grant UH242/12-1.

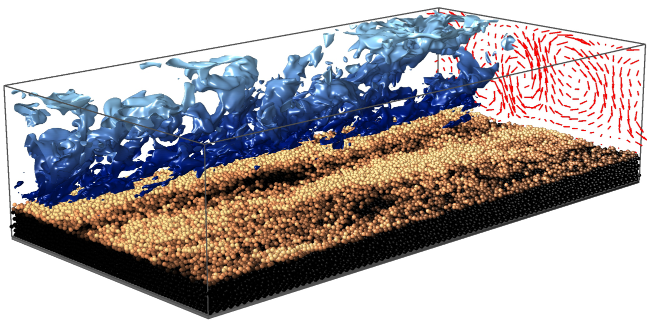

Figure 1. Instantaneous snapshot of sediment ridges and troughs together with a large–scale low–speed streak, visualised as isosorface of the streamwise velocity fluctuation u'. Brighter particle colours indicate a larger distance to the bottom wall. The mean secondary flow pattern is shown as vector plot at the downstream end of the periodic domain, main flow is from bottom left to top right. Simulation parameters: $Re_b = 9500$, $Re_\tau = 830$, $Ga = 57$, $\rho_p/\rho_f = 2.5$, $H_f/D = 25$.

References

[1] O. Flores, J. Jiménez, and J. C. Del Álamo. Vorticity organization in the outer layer of turbulent channels with disturbed walls. *J. Fluid Mech.*, **591**:145–154, 2007.
[2] J. Jiménez. Coherent structures in wall-bounded turbulence. *J. Fluid Mech.*, **842**:P1, 2018.
[3] A. G. Kidanemariam and M. Uhlmann. Interface-resolved direct numerical simulation of the erosion of a sediment bed sheared by laminar channel flow. *Int. J. Multiphase Flow*, **67**:174–188, 2014.
[4] I. Marusic, R. Mathis, and N. Hutchins. Predictive model for wall-bounded turbulent flow. *Science*, **329**(5988):193–196, 2010.
[5] I. Nezu and H. Nakagawa. *Turbulence in open channels*. IAHR/AIRH Monograph. Balkema, Rotterdam, The Netherlands, 1993.
[6] A. A. Townsend. *The structure of turbulent shear flow*. Cambridge Univ. Press, Cambridge, 2 edition, 1976.
[7] M. Uhlmann. An immersed boundary method with direct forcing for the simulation of particulate flows. *J. Comput. Phys.*, **209**(2):448–476, 2005.