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Laboratory investigation of the distribution of travel distance and rest period of sediment particles from PTV data

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We analyze paths of sediment particles on cohesionless granular bet subjected to a turbulent open-channel flow. The key objective is to provide further insights on particle dispersion including resting times. Hence, we focus on the spatial and temporal scale identified by Nikora et al. (2002) as the global range, defined as the particle path composed of many intermediate range paths, i.e with several "starts" and "stops". This requires the calculation of the probability distribution functions of particle travel distances and of rest periods.

The experimental work was performed at the Hydraulics Laboratory of IST-UL in a 12.5 m long, 0.405 m wide glass-walled flume recirculating water and sediment through independent circuits. The granular bed was a 4.0 m long and 2.5 cm deep reach filled with 5 mm diameter glass beads packed (with some vibration) to a void fraction of 0.356, typical of random packing. Upstream the mobile bed reach the bed was composed of glued particles to ensure the development of a boundary layer with the same roughness. Laboratory tests were run under conditions of weak beadload transport with Shields parameter (θ) in the range 0.007 to 0.030, Froude numbers (Fr) between 0.630 and 0.950 and boundary Reynolds number (Re_*) in the range 130 to 300.

White-coated particles with 5.0 mm diameter were introduced in the flow 3 m upstream the mobile bed reach. Particle motion was registered from above using a high-speed camera AVT Bonito CL-400 with resolution set to $2320 \times 1000\ \text{px}^2$ and frame rate of 170 fps. The field of view recorded was 77.0 cm long and 38.0 cm wide, covering almost all the width of the flume. The maximum duration of the runs was 20 min, during which more than 500 particle paths, including resting times, were registered.

The video footage was subjected to a PTV (Particle Tracking Velocimetry) developed for the problem at hand. The algorithm includes the application of Gaussian filters and thresholding operations to identify the particle. The centre of mass of the particles was determined with sub-pixel accuracy from 1D+1D Gaussian interpolation. Once particles and their centres of mass were detected, particle trajectories were reconstructed with a correlation algorithm. The stability of this algorithm limits camera framerate. Particle velocities were obtained as displacement over time interval between two consecutive frames (1/170 s).

We computed the variance of the particle positions in both directions x (longitudinal) and y (cross-stream). We determined the exceedance distribution function of the travel distance X, defined as $P(X > x)$, and of resting times, T, $P(T > t)$. These distributions are said to be heavy-tailed if their tails have a slope, in log-log coordinates, larger than 2. Hill's estimator was used to compute this slope following the arguments of Hassan et al. (2013). It is known that these distributions depend on flow conditions, bed material and composition and existence/type of bed forms (McNamara and Borden, 2004; Ferreira et al., 2015), which may bring about strong deviations from the gamma probability function.

Our results confirm the existence of a subdiffusive range of scales, even for the limited time-spaced window of observation. The distribution of the travel distance does not seem to be heavy-tailed. This may be an artifact of the short observation window but can also be explained by the relatively simple bed morphology associated to artificial sediment with one single diameter. In this case, the explanation for heavy-tailed distribution of travel distances should lie essentially effects of channel morphology (Lamarre and Roy 2008). Conclusions about the distribution of resting times are conditioned by the time window employed for particle tracking and number of stops detected. Preliminary results indicate that the distribution is not always heavy-tailed.

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