A generic Froude scale model study of massive bedload deposition in a debris basin

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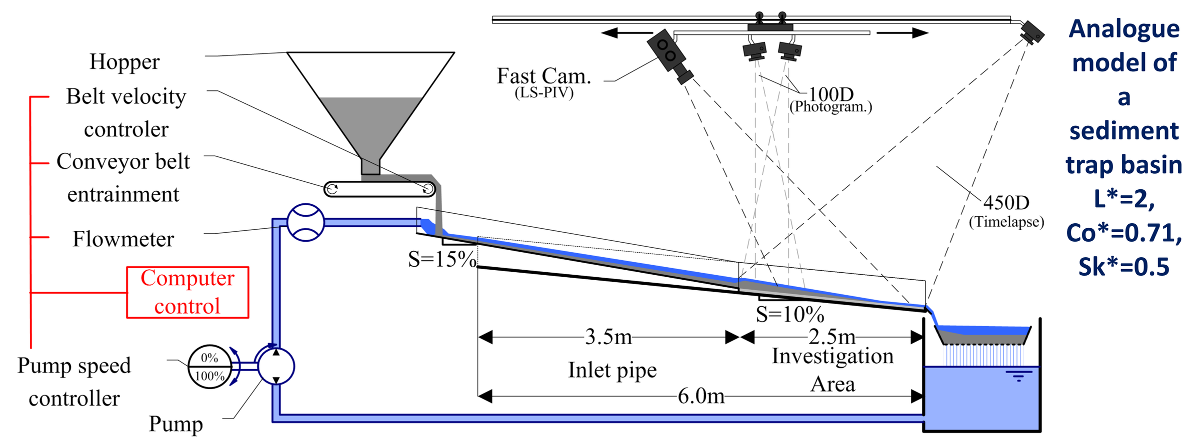
1. Introduction

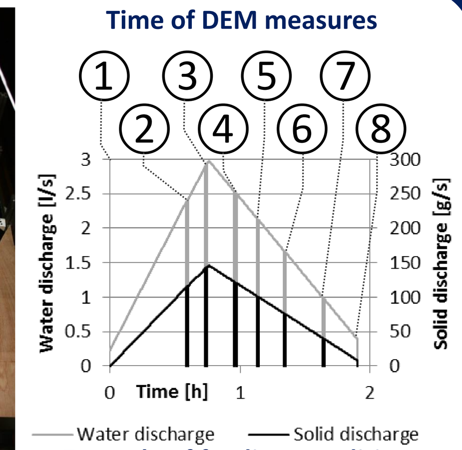
In steep slope streams and especially in their fan part, torrential floods mainly result from **abrupt and massive sediment deposits**. Since the 1970s, debris basins complete reforestation, erosion control and check-dams in torrent-hazard mitigation. Piton and Recking (2016) demonstrated that **if design criteria exist for the structure itself, little information is available on the dynamic of the in-basin sediment depositions.**
Small scale experiments have been undertaken to acquire new data on this subject.

2. Flume set up

A 6-m-long, 1.2-m-wide, 0.4-m-deep, 10% steep, titling flume is used. The water discharge varies, with a maximum of 3 l/s. The sediment feeder is composed of a hopper associated with a conveyor belt with a maximum solid discharge of 300 g/s installed in a **sediment-fed configuration**. The sediment mixture consisted in **natural poorly sorted sediments** (D=[0.2;20 mm]). The model was assumed to be an **analogue model** following the definition of Peakall et al. (1996).



Analogue model of a sediment trap basin L*=2, Co*=0.71, Sk*=0.5

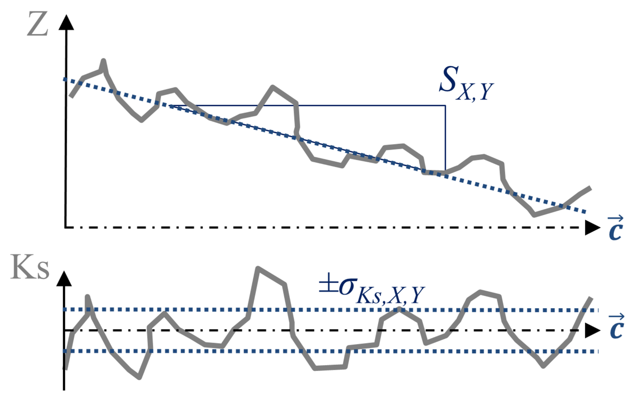


Example of feeding conditions

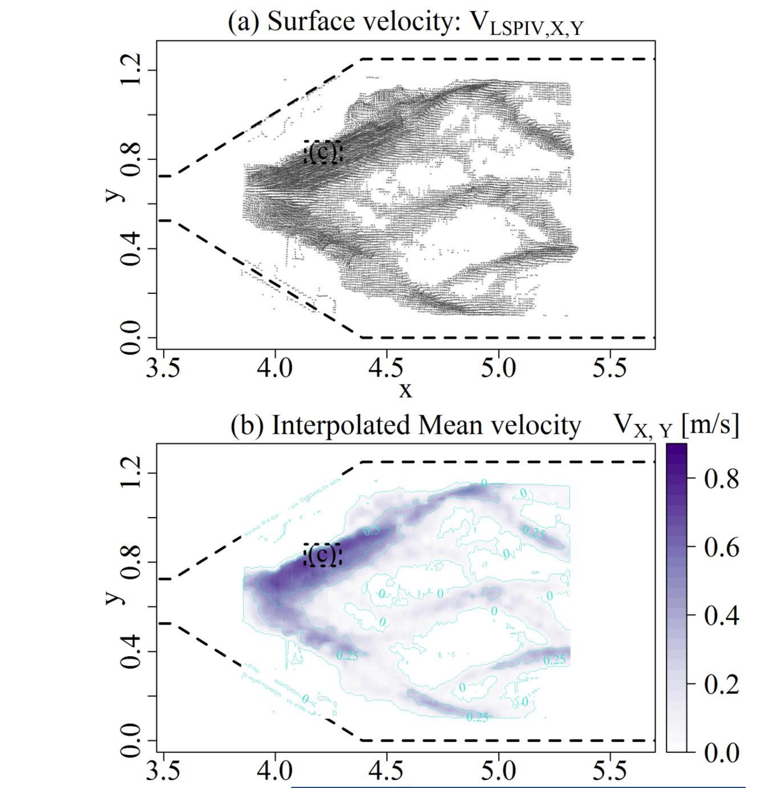
3. Relief and flow measure and reconstruction

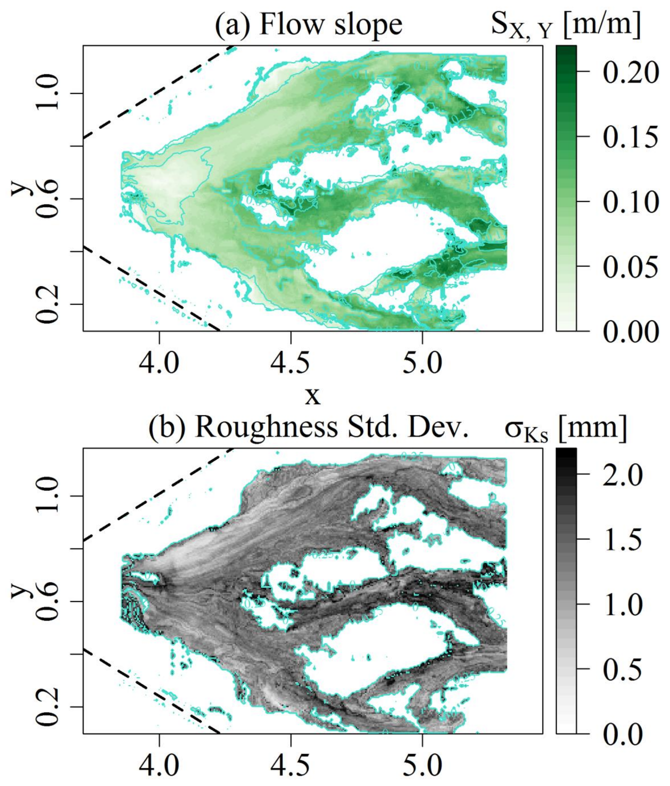
Flow fields over massive bedload deposition are complex and complicated to measure. A new measurement procedure has been created to benefit from image analysis methods: Large Scale Particle Image Velocimetry (LS-PIV) and Structure-from-Motion photogrammetry (SfM). Both of them fuel an inverse method to fully reconstruct 2D flow fields.

Slopes (a) and roughnesses (b) are extracted from the SfM-DEM along the stream lines, deduced from the LS-PIV measures



The surface velocity is measured using the LS-PIV method (a). The mean-depth velocity is interpolated on all the flooded area (b).





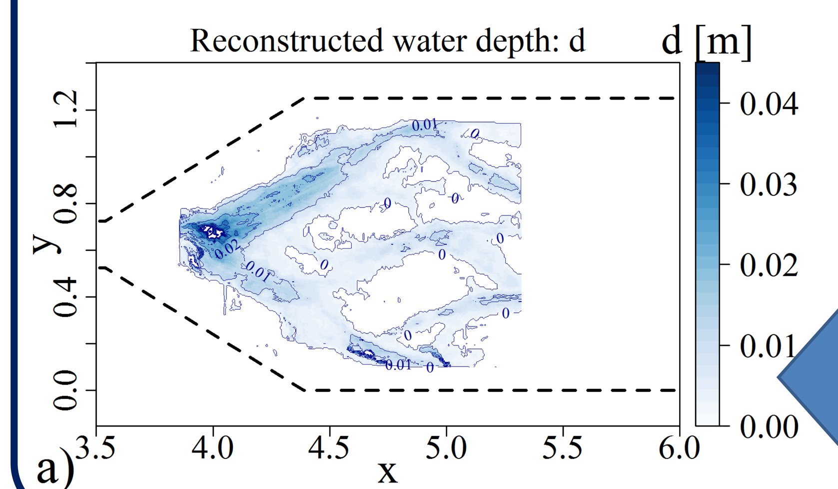
Velocity measurement: *V*
LS-PIV (image analysis)

Relief measurement (Slope *S*, Roughness *Ks*)
SfM (Photogrammetry)

Friction law independant validation
V=f(H,S,Ks)

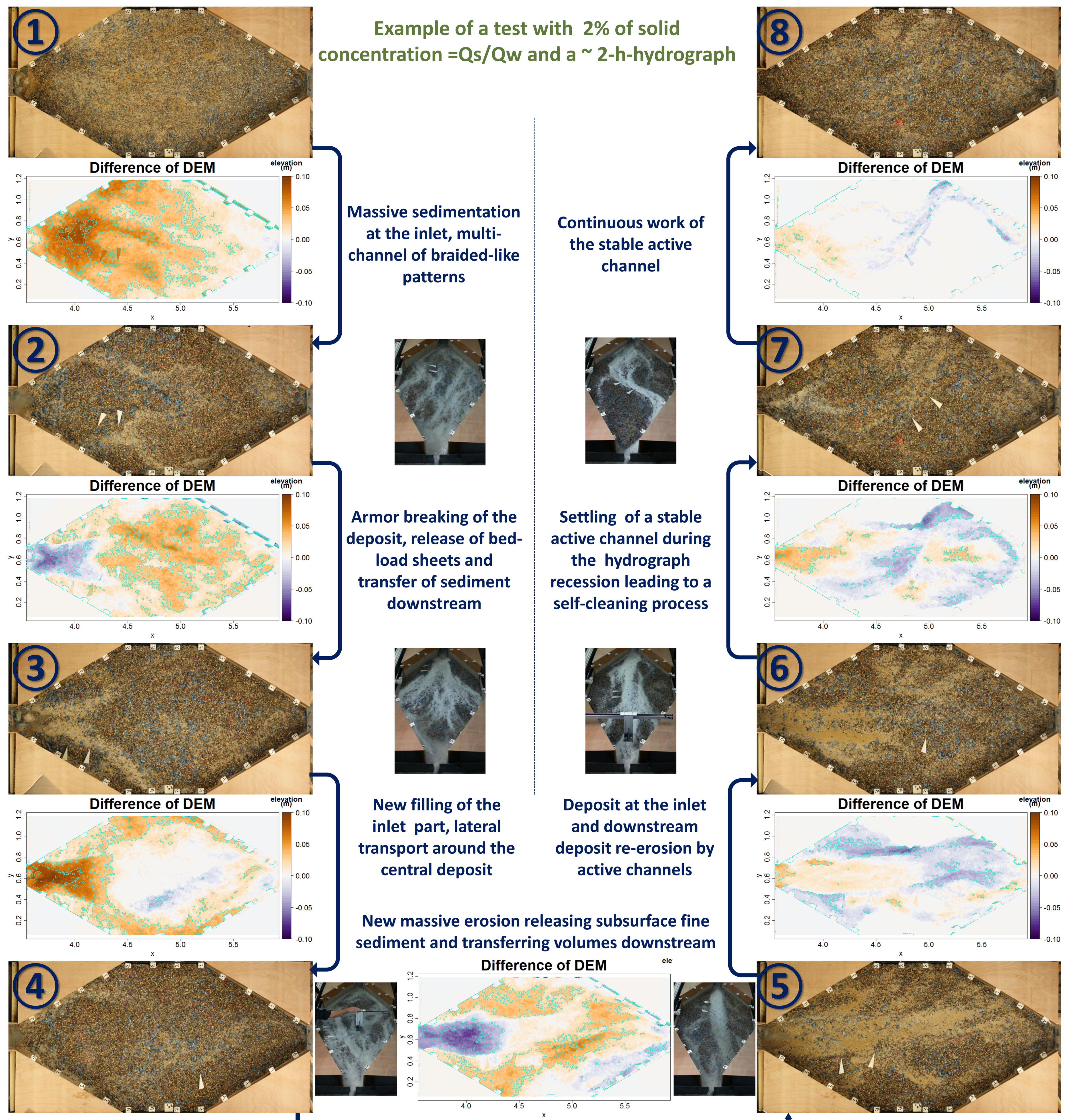
Water depth *H* reconstruction by friction law inversion
H=f⁻¹(V,S,Ks)

Full reconstruction of 2D flow fields
H, V, S, Ks



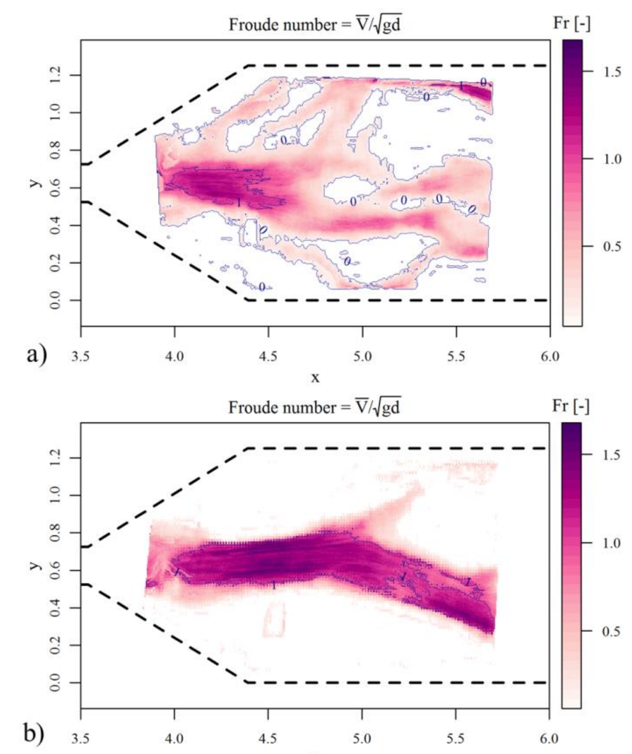
4. Geomorphological analysis

Bed state, roughness, erosion and deposition are meaningful indicators of the morphodynamics of massive bedload deposition. The process has strong similarities with alluvial fan construction, although at a smaller and much faster scale. Significant **grain size sorting effects** were observed and **strongly influenced** the **solid transport** and **changes in the deposit morphologies**. The basin fillings occur in cycles of multi-threads flow with deposition near the inlet followed by armor breaking leading to flow channelization, bed-load sheet releases and massive transport further in the trap, under the form of lobes. Overall the morphology is not constant but cyclic.

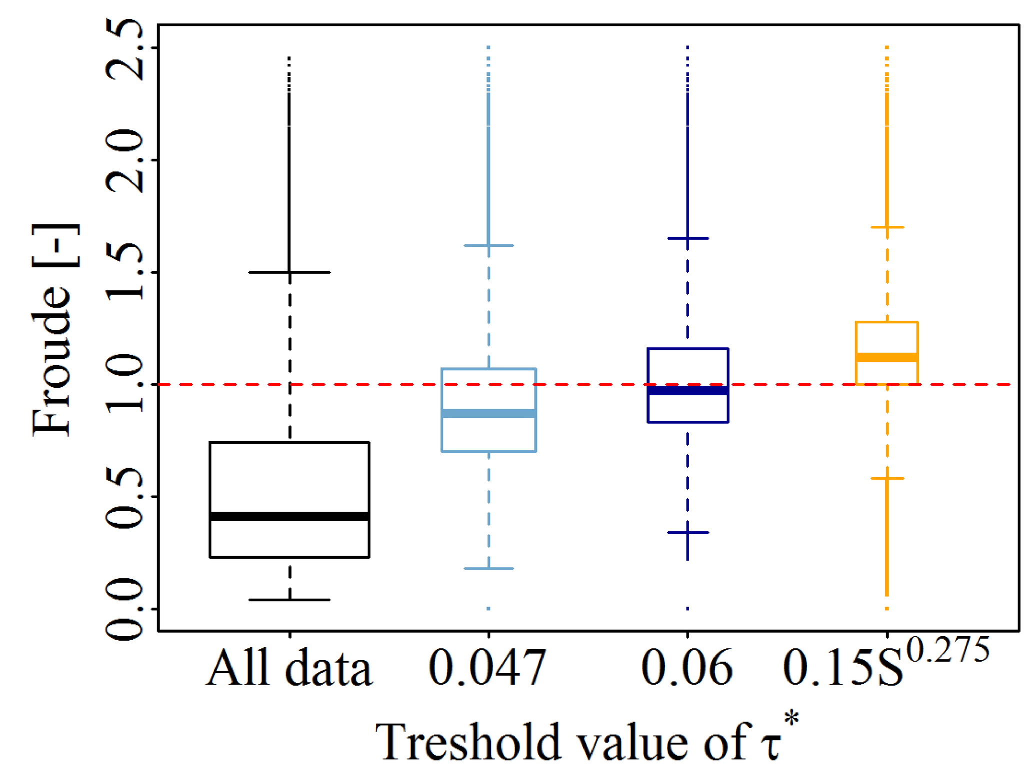


5. Froude number: self-organized critical state

The Froude number $V/\sqrt{gd}$ have been computed on this changing morphology. This dimensionless parameter, computed from three independent measures (Velocity, Slope & Roughness), is an interesting proxy of the flow type. The braided patterns usually experience **sub-critical** flows, despite the **steepness** of the deposit, while armor-breaking, incised morphology, with higher transport efficiency, experienced **near critical Froude** number, i.e., morphological flows built the system toward the lower flow energy state.



Froude number reconstructed for (a) a braided morphology, mostly subcritical, and (b) an incised, single thread morphology, mostly near-critical



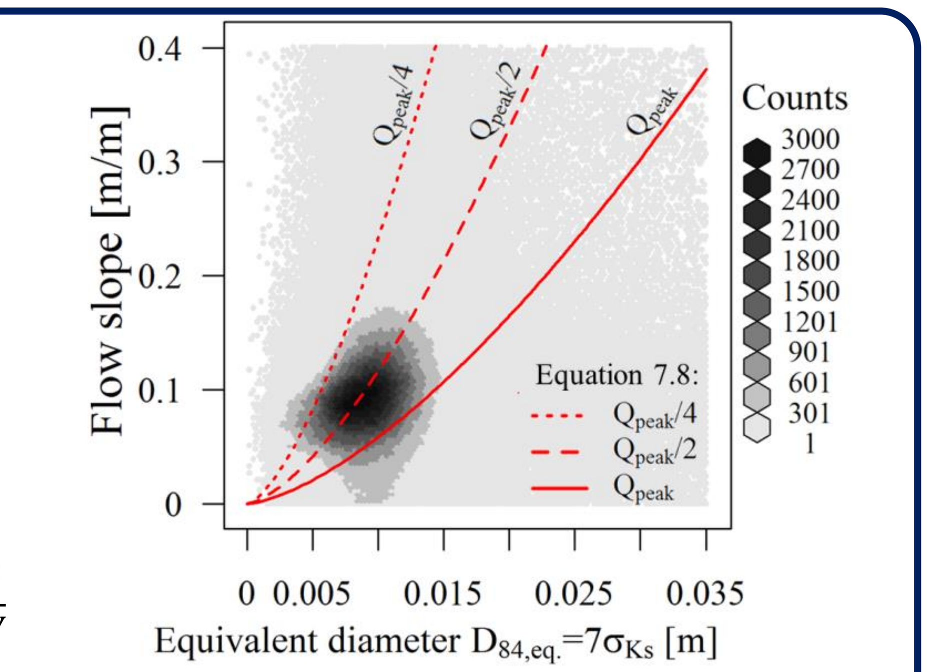
Froude number statistics of the complete dataset (~1.7M data), mostly subcritical, and filtered with varied threshold value of Shields number, highlighting that morphologically active flows (i.e., $\tau > \tau_{cr}$) approach a critical Froude number

6. Deposition slope

Alluvial fan creations are often suspected to settle close to the critical shear stress. Rearranging a fusion of the Rickenmann and Recking (2011) friction law, with the slope-dependent, critical Shields equation proposed by Recking et al. (2008) gives a deposition slope S estimation from the grain size, discharge and flow width:

Eq. 7.8 of Piton (2016): $$S = 0.64\,\frac{D_{84}^{1.5}}{Q/W}$$

Applying this equation to the whole dataset show promising results : the point cloud is centered on the mean test discharge.



Locally measured flow slope VS diameter deduced from the roughness, compared to Eq. 7.8: the deposition slope order of magnitude seems correctly estimated

References:
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