Dynamics of a fine and coarse sediment mixture using a medical CT scan

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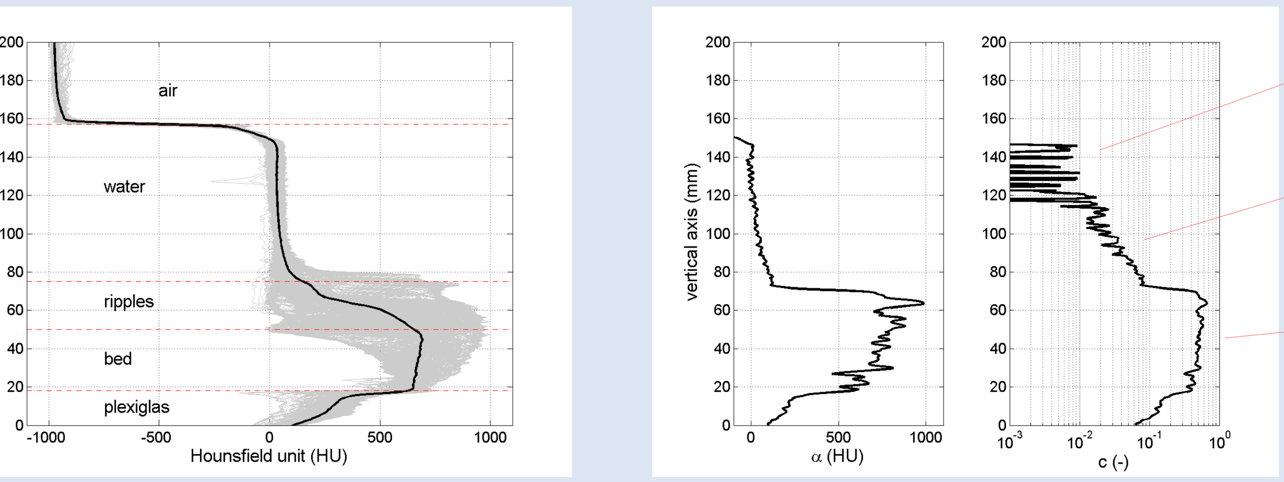
Context and objectives of the study: Dynamics of a sediment mixture

- Typical issue for **alpine rivers** where **poorly sorted sediments** are found
- A long history in **laboratory experiments**:
  - Many studies with unimodal sediment (starting from Shields, 1936)
  - Some studies with bimodal/multimodal mixture including gravel/silt (Gravel/sand : Wilcock and Southard, 1988; Patel and al., 2013)
  - Few experiments on fine sediment dynamics over a coarse matrix (Grams & Wilcock, 2007, 2015 ; Kuhnle et al., 2013, 2017)
  - Very few experiments on fine sediment dynamics over a mobile coarse matrix (Venditti et al., 2010 ; Barzilai et al., 2013 ; Perret et al., 2015, 2017)
- **Objectives of the study**
  - Evaluate fine sand dynamics on a coarse matrix (ripples, bedload and suspension)
  - Estimate impacts of a clogged bed on coarse sediment bedload transport

Interest and use of the CT-scan

- **Provide a 3D description of the density**
  - 3D attenuation coefficient matrix scaled in Hounsfield unit (HU) which are related to matter density : α_{air} = -1000 HU; α_{water} = 0 HU; α_{quartz} = 1500 HU
  - 1 voxel : 0.6x0.6x2mm
- Estimation of **the porosity / concentration of sediments**

$$c=\frac{\alpha-\alpha_{water}}{\alpha_{quartz}-\alpha_{water}}$$



Too uncertain for c<10^{-2} (C<20 g/l) !

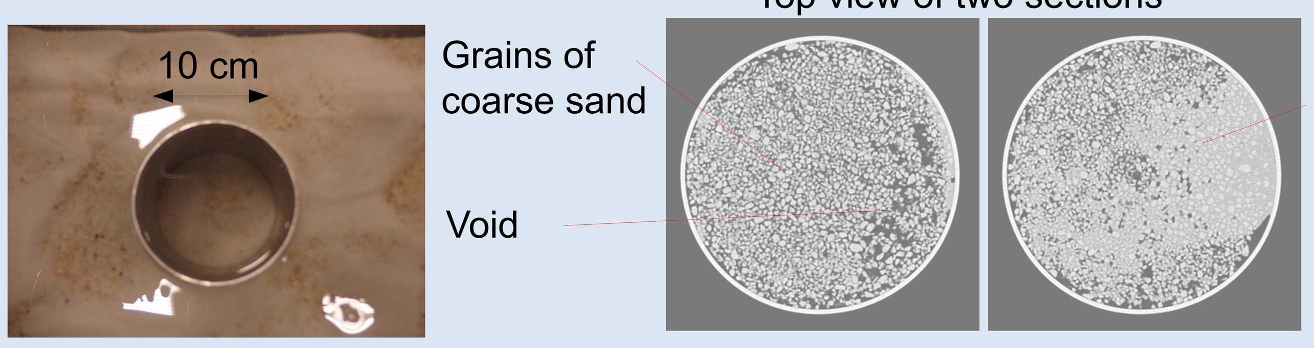
Overestimation of C due to dynamic scan ?

Porosity increasing from 0.4 (z=60mm) to 0.6 (z=20mm) Infiltration of fines ?

Example of vertical profiles of 3D attenuation coefficients for a specific cross-section of the experiment and corresponding vertical concentration profile estimated

- Estimation of **infiltration of fines in the coarse matrix**

Need to be validated for a dynamic scan; possibility to do a static scan with a sample taken after the experiment (commonly done for sediment core, Crémer et al., 2002) → difficulty to take the sample without modifying the structure...



- Estimation of the **air/water and water/bed interfaces**→ 2D vue of the water depth and bed structures

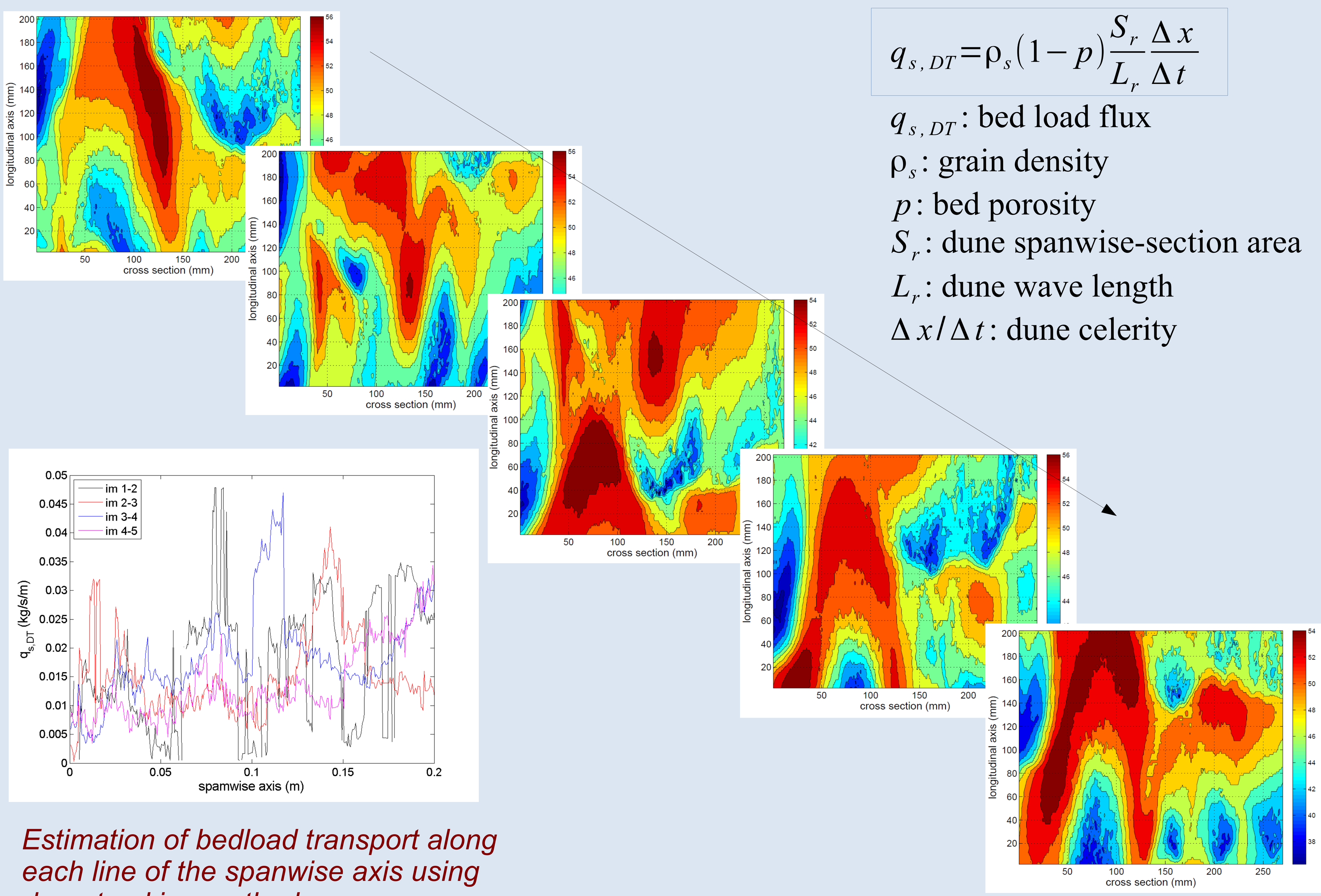
Critical values in HU to be estimated : $\alpha_{water/bed}$ ≈ 300 HU

Possible statistical analysis of bed structures (Marion et al., 2003)

- Possible **estimation of bedload** using « dune tracking » method with multiple scans

$$q_{s,DT}=\rho_s(1-p)\frac{S_r}{L_r}\frac{\Delta x}{\Delta t}$$

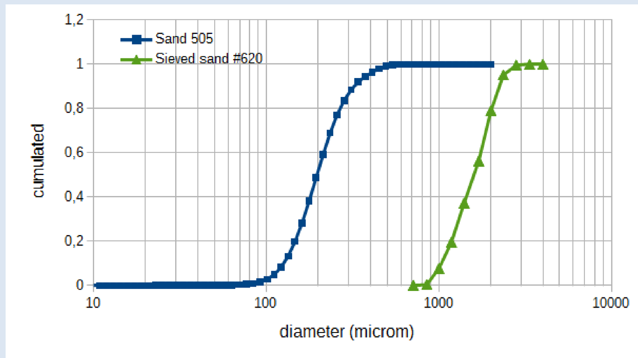
$q_{s,DT}$: bed load flux
ρ_s : grain density
p : bed porosity
S_r : dune spanwise-section area
L_r : dune wave length
$\Delta x/\Delta t$: dune celerity

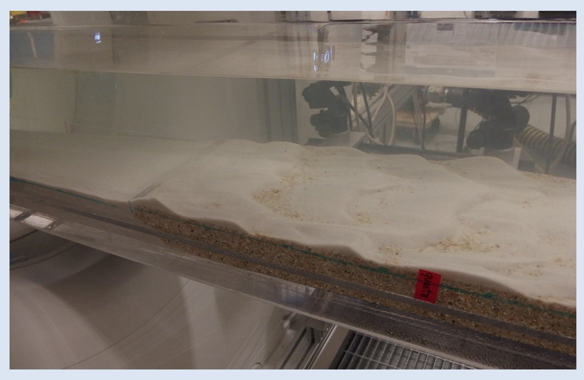


Estimation of bedload transport along each line of the spanwise axis using dune-tracking method

Experimental set-up

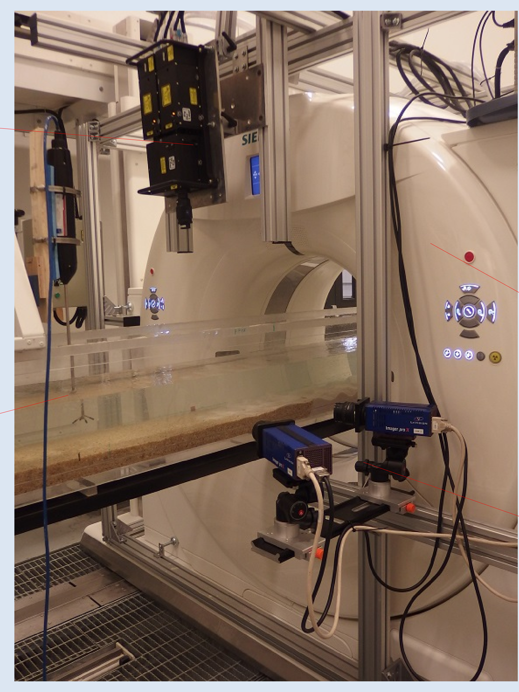
- Use of a small horizontal channel (0.305x0.30x7m) with a coarse bed matrix 6 cm thick (d_c=1.5 mm) and a fine sand reservoir upstream (d_f=0.2 mm) of pure silice (99%)

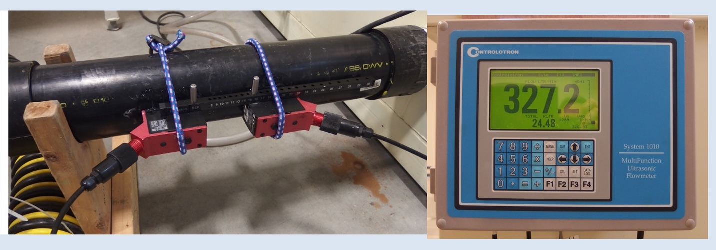


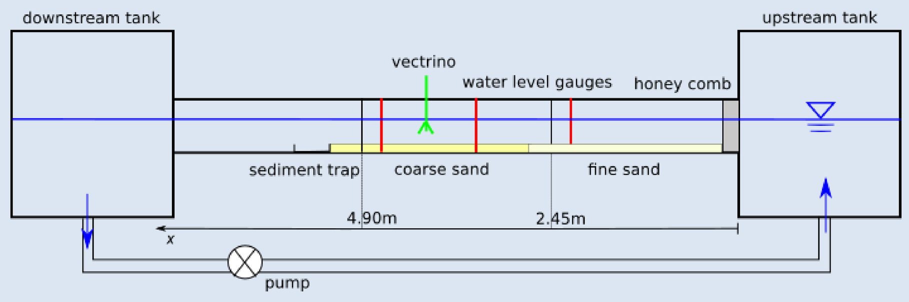


Propagation of fines sands over the coarse sand matrix

- High definition insctrumentation



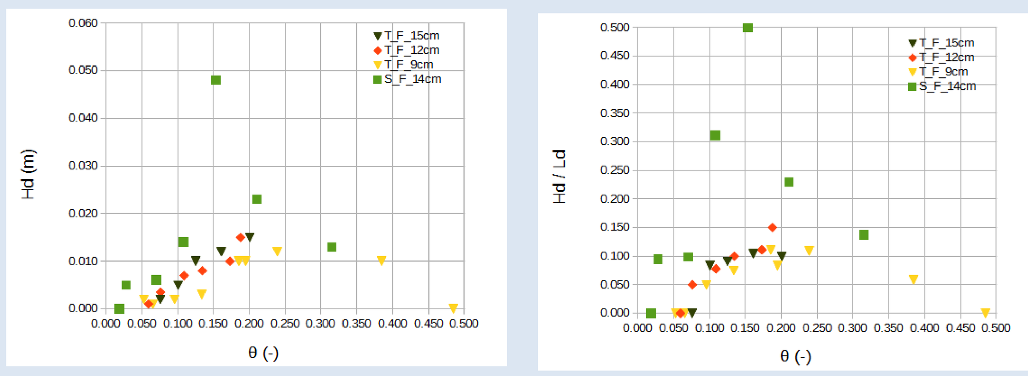




Schematic view of the experiment

Sediment transport : ripple characteristics

- Estimation of ripple height and steepness for fine sand alone

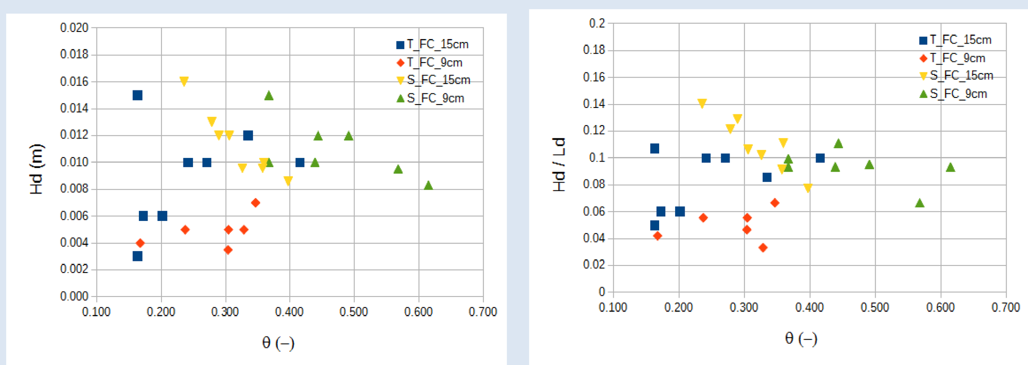


Small values compared to literature (not in equilibrium?)

$H_r/L_r\approx 1000\,d_{50}\approx 0.2$
$H_r\approx 150\,d_{50}\approx 3\,\mathrm{cm}$

Impact on bed shear stress to be discussed with vectrino and PIV results

- Ripple characteristics for fine sand on a coarse matrix



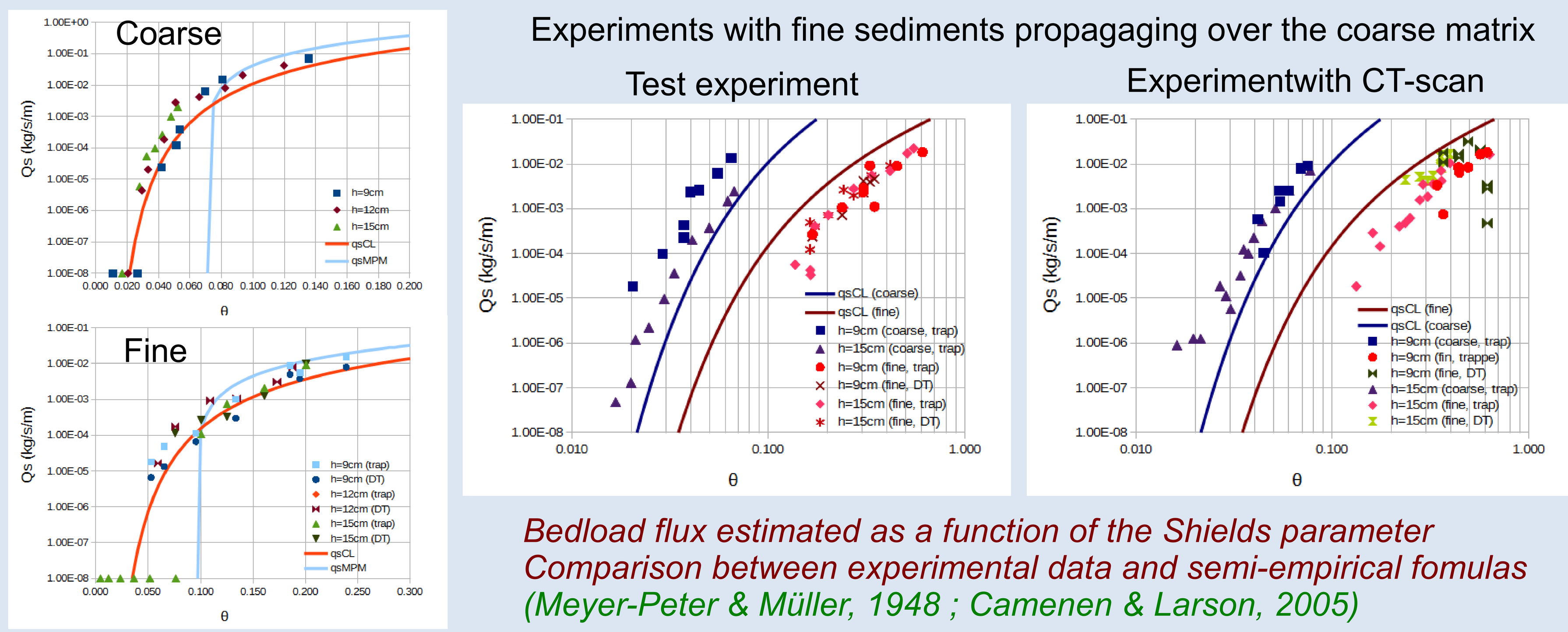
Similar results as for fine sand alone

Smaller ripples expected (underestimated in the test exp. ?)

Presence of ripples for larger bed shear stresses

Sediment transport : bedload flux

- Synthesis of the results for test experiments and experiments using CT-scan



Bedload flux estimated as a function of the Shields parameter
Comparison between experimental data and semi-empirical fomulas (Meyer-Peter & Müller, 1948 ; Camenen & Larson, 2005)

- Reduction of the fine capacity (trapping effect) and increase of the coarse capacity (lubrification effect)

Results from dune tracking with the scan overestimated apart for two cases (high bed shear stress, ripples half-washed); Skin bed shear stress estimated using log friction law with $k_s=2d_{50,c}$

Conclusions and perspectives

- Interaction between fine sediments infiltrated on a coarse matrix and coarse sediments (new data set for bedload and suspended load with detailed hydrodynamics and ripple characteristics)
- Possible comparisons of methodologies (Vectrino and PIV for flow measurements, dune-tracking methodologies -moving volume or surface PIV + active layer-, sediment trap and dune-tracking results)
- Limitation of the CT-scan (need of improving images reconstructions with more accurate HU values, infiltration quantification, ripple characteristics)