Towards a statistical modeling of contact erosion from pore-scale flow measurements in a porous medium over a sand layer

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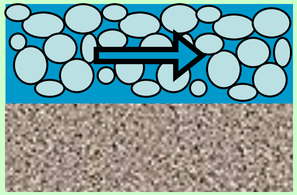
To better reflects its missions, Cemagref becomes Irstea.

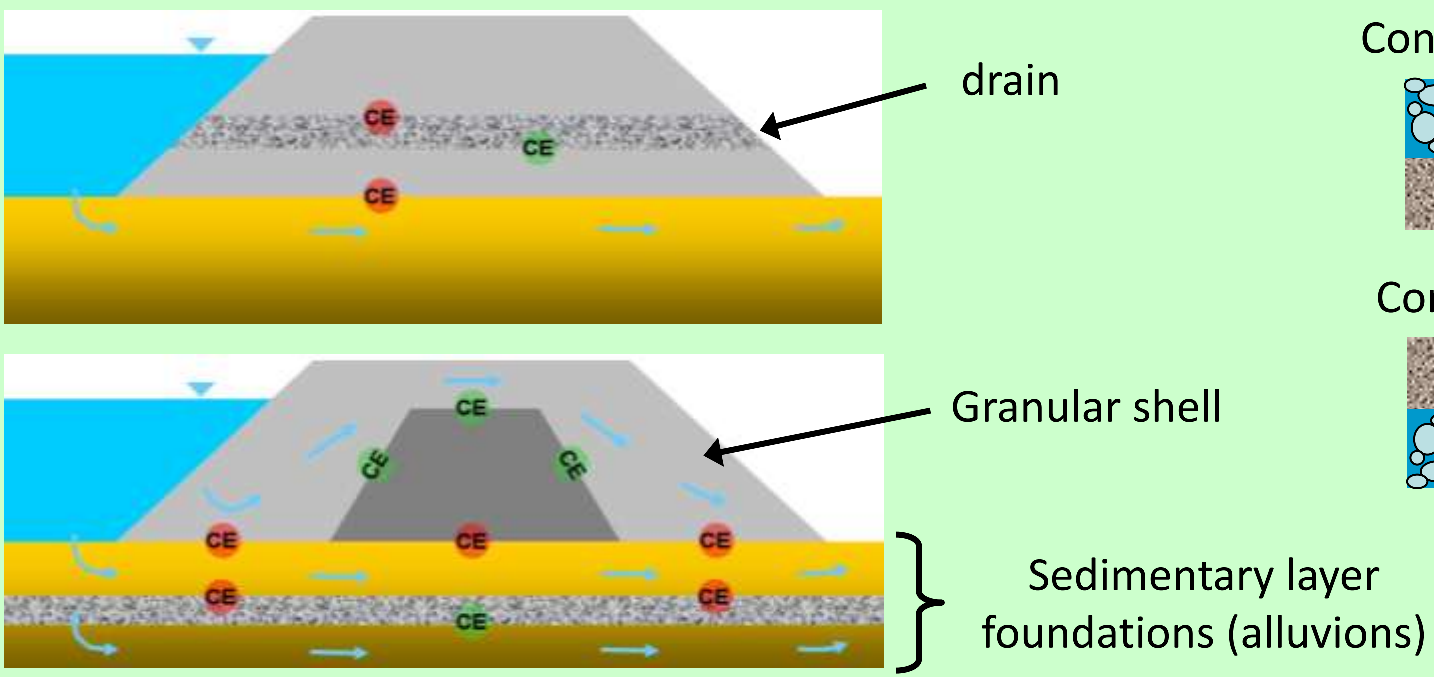
Acknowledgment:

Motivation

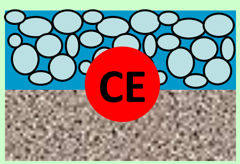


Contact erosion: erosion by a tangential flow at the interface between two soil layers with a high contrast in permeability

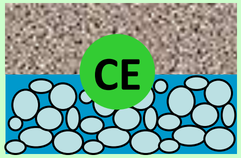
→ high-concern for **fluvial levees**



Configuration 1

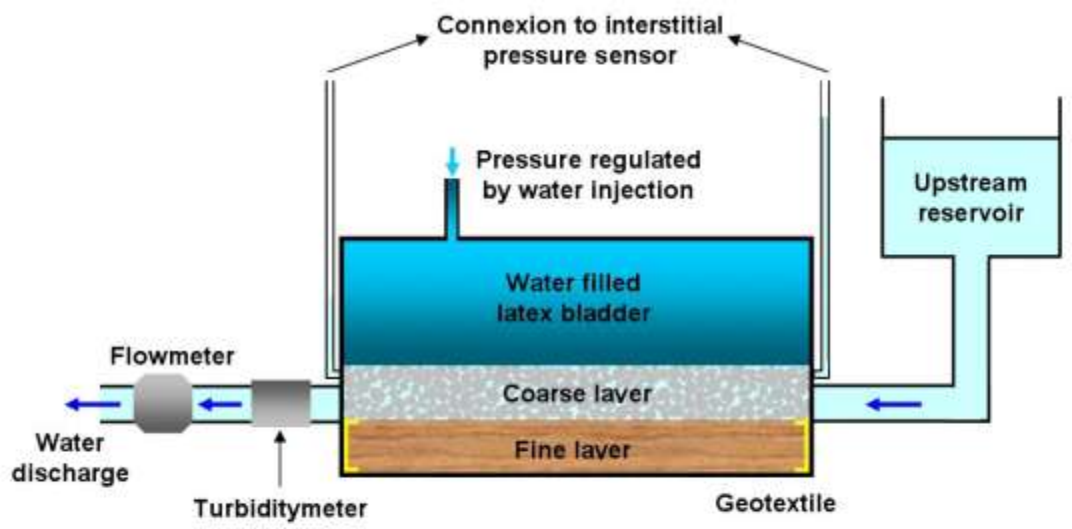


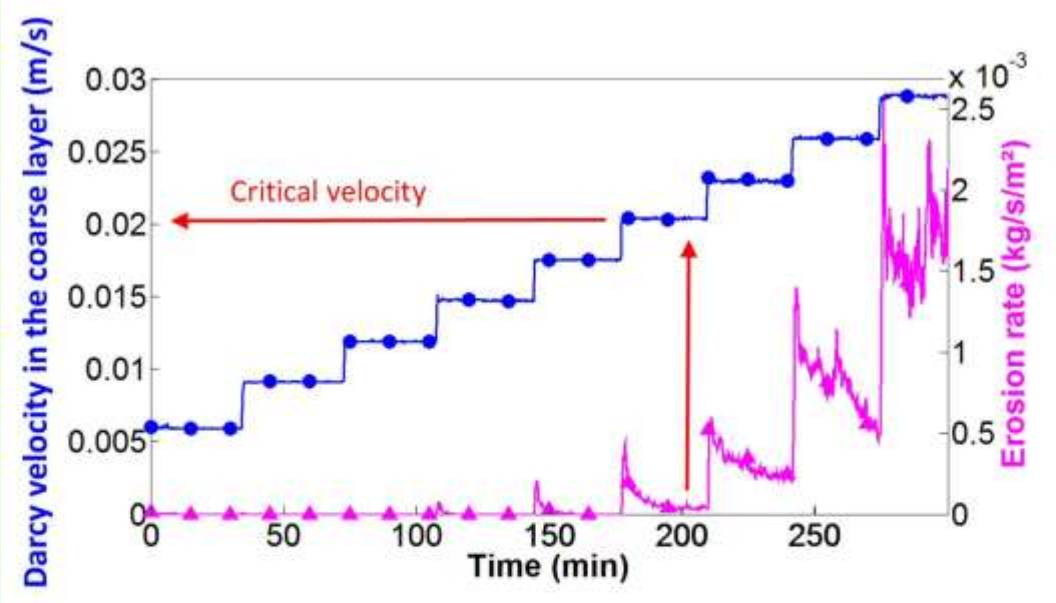
Configuration 2



At the sample scale

Experimental device at LTHE (Grenoble)

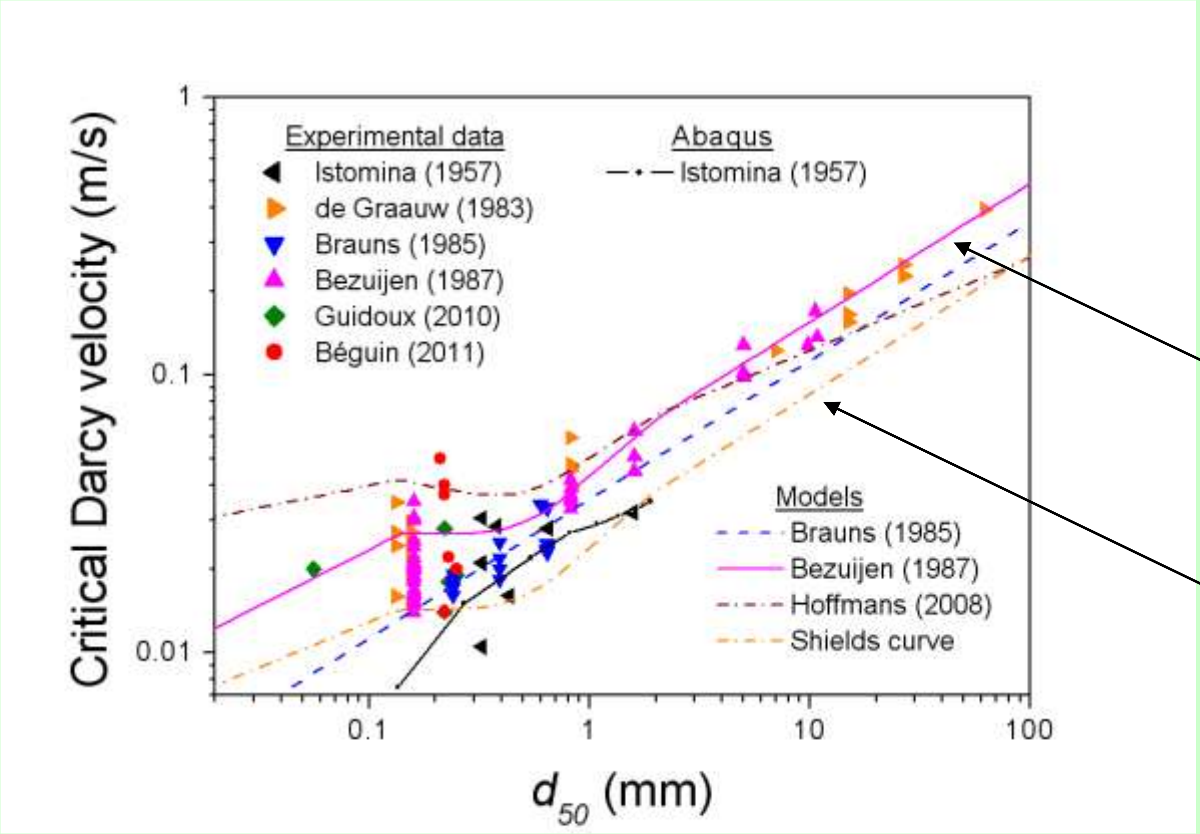




Typical results of a CE test (Guidoux, 2010)

At the sample scale

<u>Concern #1</u>: **Under-estimation** of U_c from Shields diagram

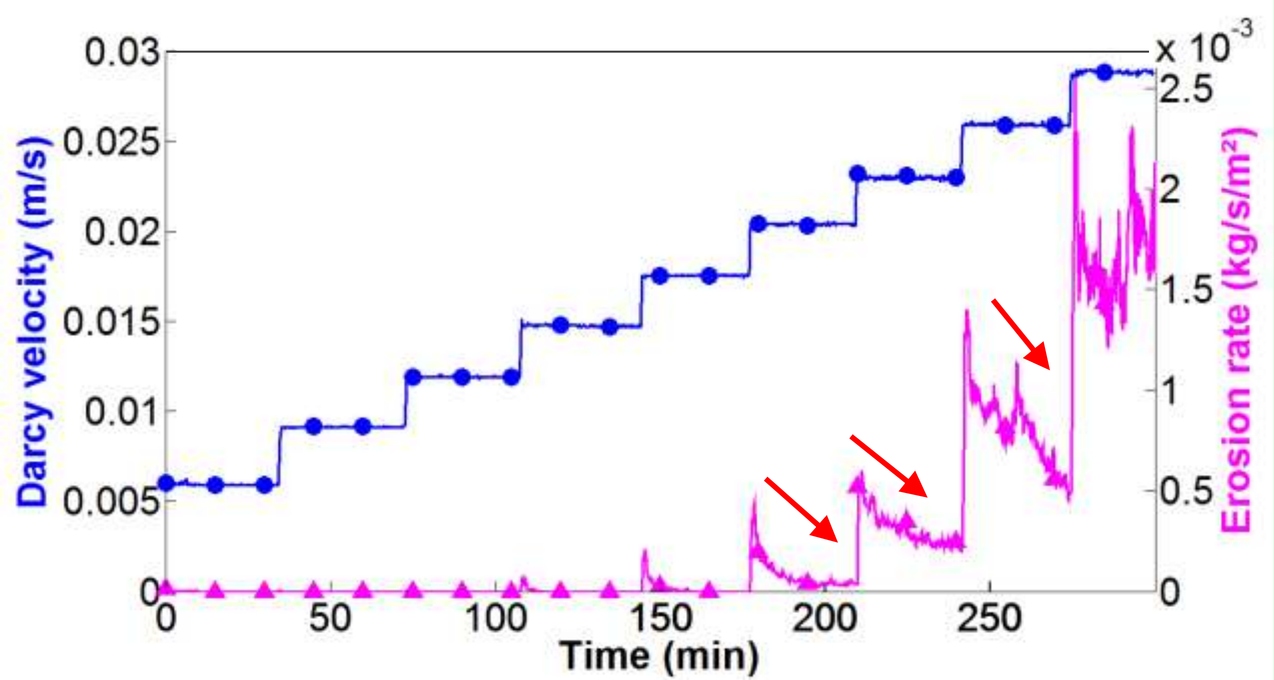


Shields diagram + empirical coefficient close to 2

Shields diagram

At the sample scale

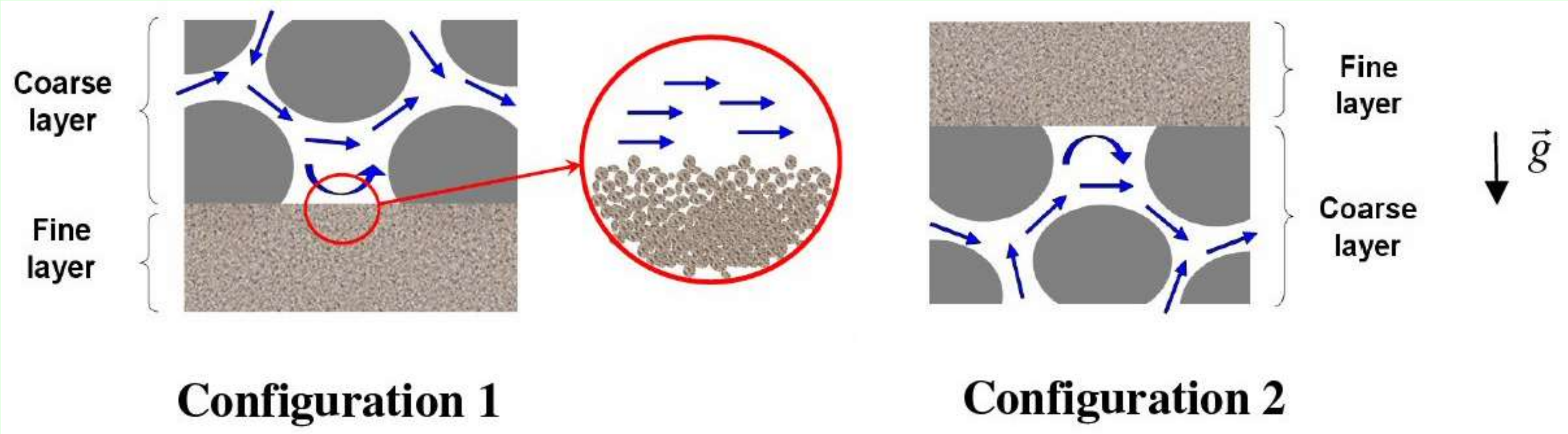
Concern #2: **Time effect** (relaxation after each velocity step)



→ **paving** at the upper surface induced by **grain sorting**

At the pore-scale

Contact erosion: surface erosion in a porous environment



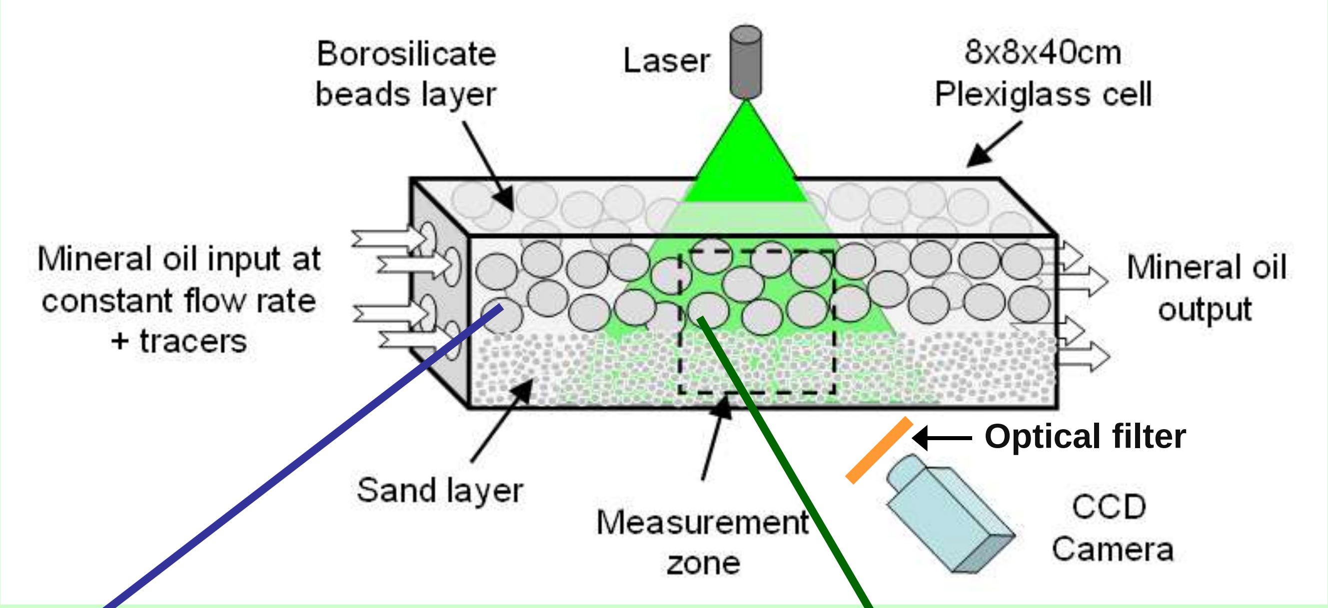
hydraulic criterion + **geometric** criterion

Erosion at the surface of the fine soil

Fine transport in the pore space

↳ **hydrodynamics in the contact zone**

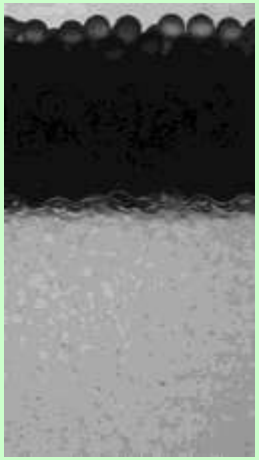
Set-up and optical techniques



Index-matched medium

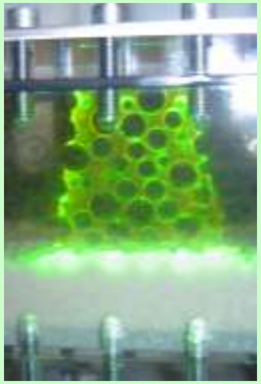
Borosilicate glass beads
(d=7.3mm; 9.7mm)

Mineral oil mixture
($\mu=18.3\times10^{-6}$ Pa.s)

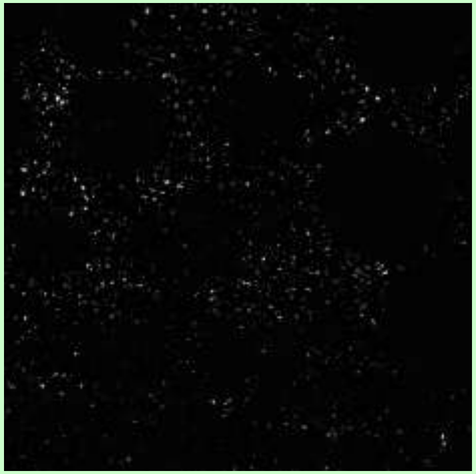


Laser induced fluorescence

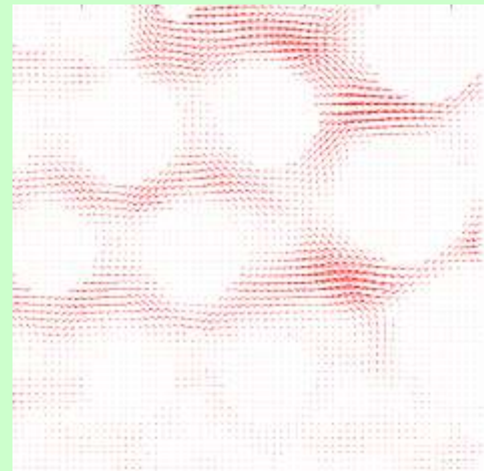
Fluorescent tracers

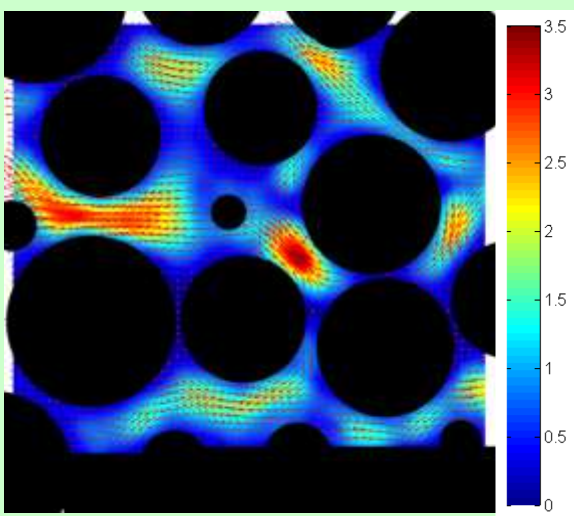


Post-processing: PIV



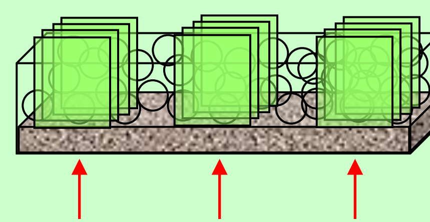
PIV algorithm (DPIVsoft) with a mask



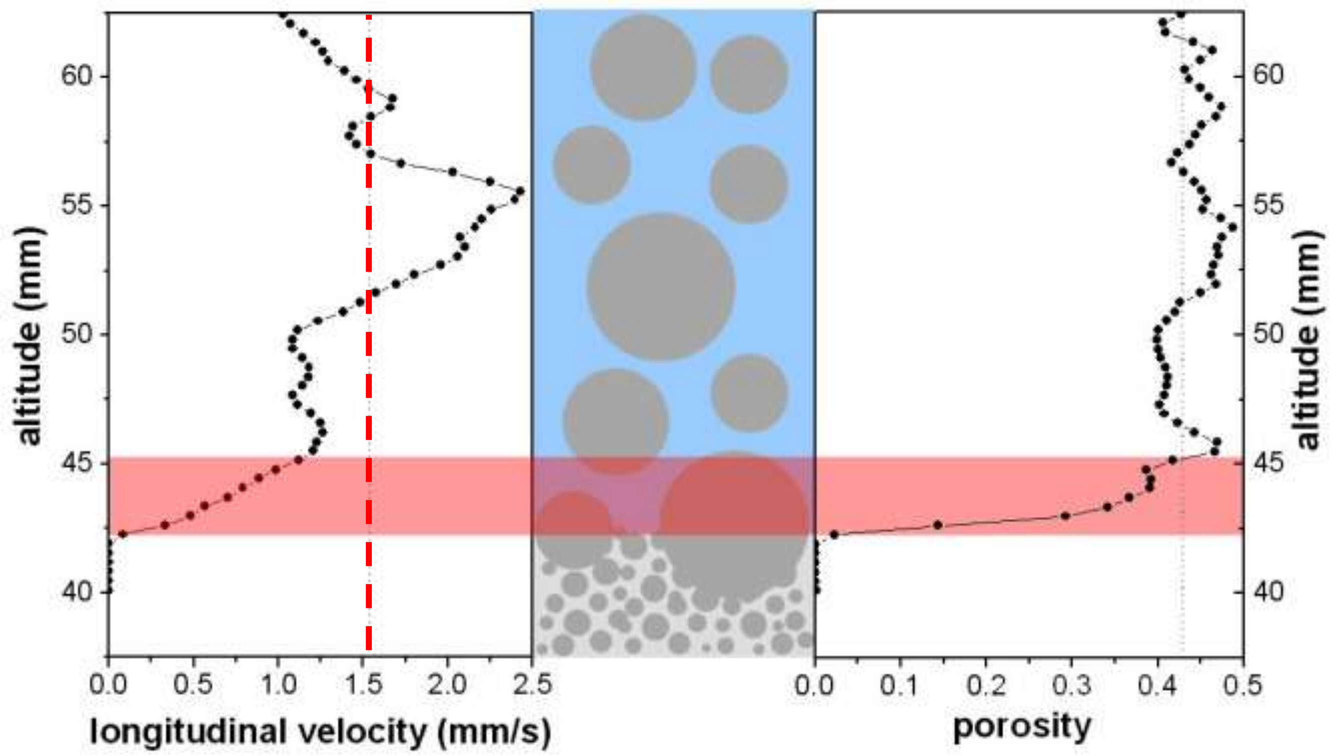


Time averaging over 250 raw fields

+ Space averaging



Transition zone

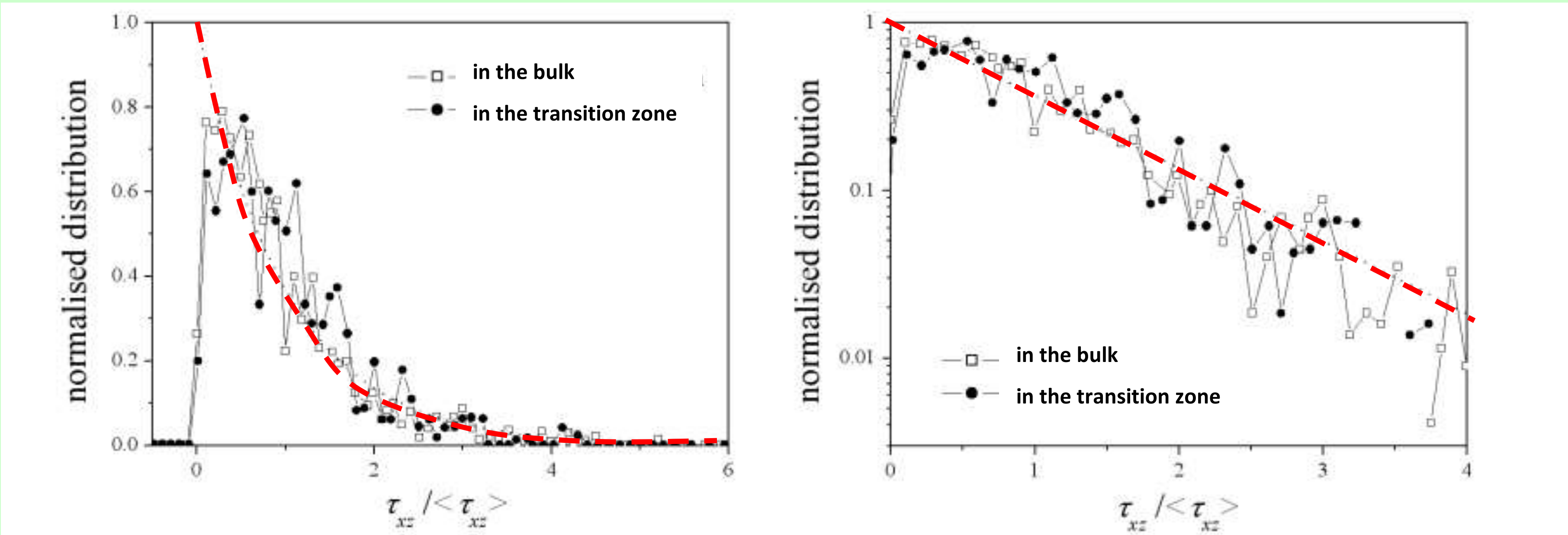


→ high spatial variability

→ correlation porosity/velocity

→ relevance of the mean velocity?

Shear-stress distribution



→ the spatial variability of the flow is very well accounted for by an **exponential distribution** of the shear stresses

$$f(\tau) = \frac{1}{\langle \tau \rangle} \exp\left(-\frac{\tau}{\langle \tau \rangle} \right)$$

→ **Stabilising effect** of the transition zone

$$\langle \tau \rangle_{transition} \approx 0,5 \langle \tau \rangle_{bulk}$$

Consequence on the critical velocity

Mean shear stress at the interface

$$\langle\tau\rangle_{transition} = \tau_c^{Shields}$$

Mean shear stress in the porous medium

$$\langle\tau\rangle_{bulk} \approx 2\langle\tau\rangle_{transition}$$

Critical gradient

(Wörman et al., 1992)

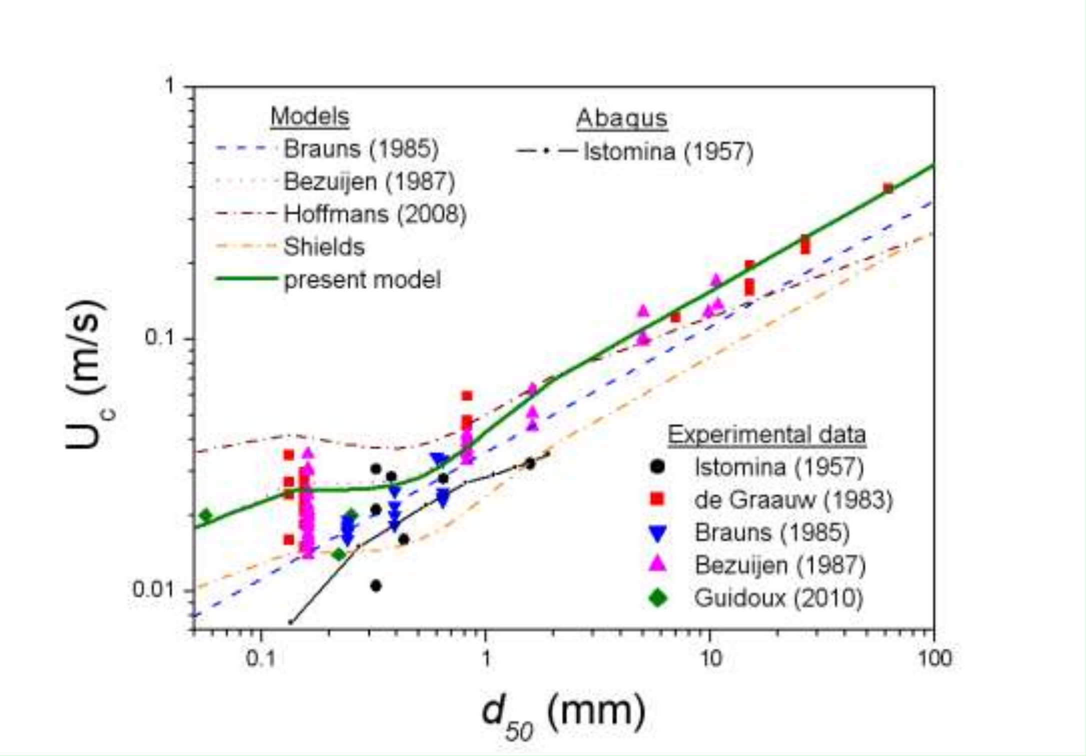
$$i_c = \frac{A_S \langle\tau\rangle_{bulk}}{\beta_w n_D \rho_w g}$$

Flow law

$$i = aU + bU^2$$

Critical velocity

$$U_c$$



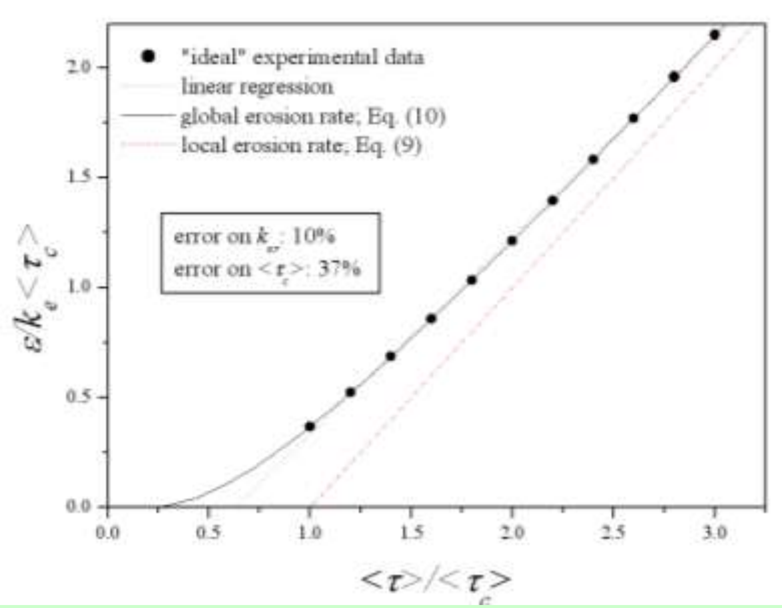
→ ANSWER TO CONCERN #1

Stochastic modeling of contact erosion

(H1) local erosion law: $\varepsilon = \begin{cases} k_{er}(\tau - \tau_c) & \text{if } \tau > \tau_c \\ 0 & \text{else} \end{cases}$

(H2) exponential distribution of the bed shear stresses

$$\langle \varepsilon \rangle = \int_{\tau_c}^{+\infty} f(\tau).k_{er}(\tau - \tau_c)\, d\tau = k_{er} \langle \tau \rangle \exp\left(-\frac{\tau_c}{\langle \tau \rangle} \right)$$

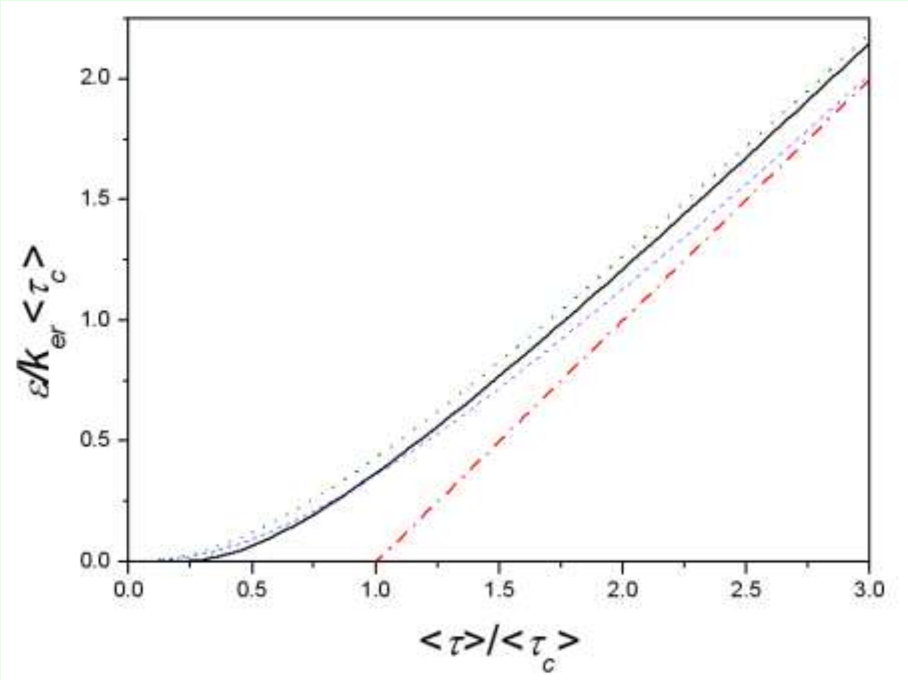


→ Possible experimental bias on erodibility parameters!

Stochastic modeling of contact erosion

(H3) normal distribution of the soil critical shear stresses

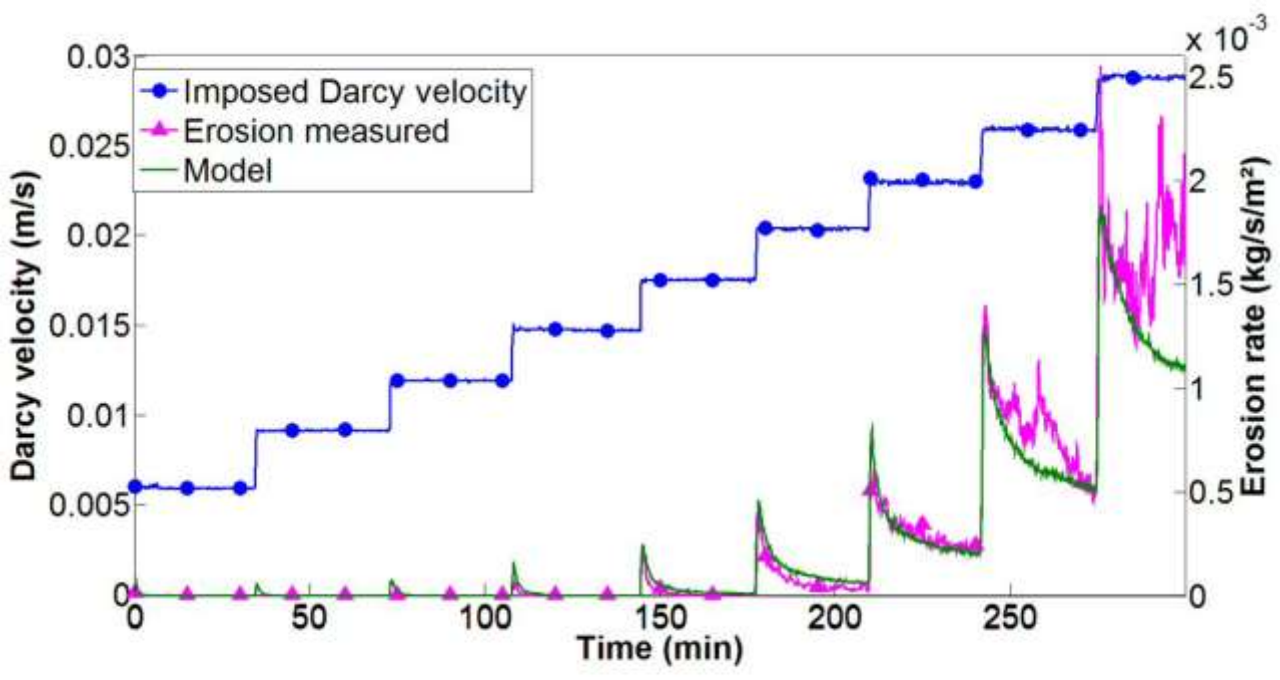
$$\langle \varepsilon \rangle = \int_0^{+\infty} \int_{\tau=\tau_c}^{+\infty} f(\tau) g(\tau_c) k_{er} (\tau - \tau_c) d\tau_c d\tau = \int_0^{+\infty} k_{er} g(\tau_c) \langle \tau \rangle exp\left(-\frac{\tau_c}{\langle \tau \rangle} \right) d\tau_c$$



→ small effect, even for a broad distribution

Stochastic modeling of contact erosion

(H4) renewal of the soil critical shear stress when erosion exceeds locally a characteristic depth (=intrinsic length scale of the soil)



→ good agreement with only two free parameters

→ ANSWER TO CONCERN #2

Conclusions

- Specificity of contact erosion: high **spatial variability** induced by the pore geometry in the coarse soil layer.

- Existence of a **transition zone** with a **safety effect** against the risk of contact erosion.

- **Statistical** distribution of longitudinal component of the **shear stress** is compatible with an **exponential law** in the **transition zone** and in the rest of the porous layer.

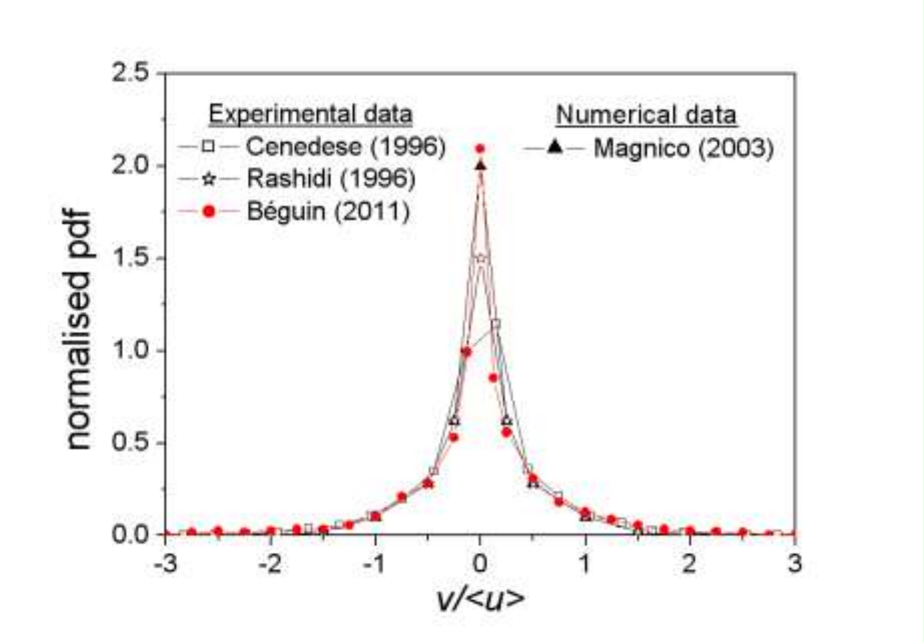
- **Stochastic** modeling of contact erosion: good agreement with experiments.

- More details in *Beguin, Philippe & Faure, J. Hydraulic Engineering (to be published soon)*.

Thank you for your attention…

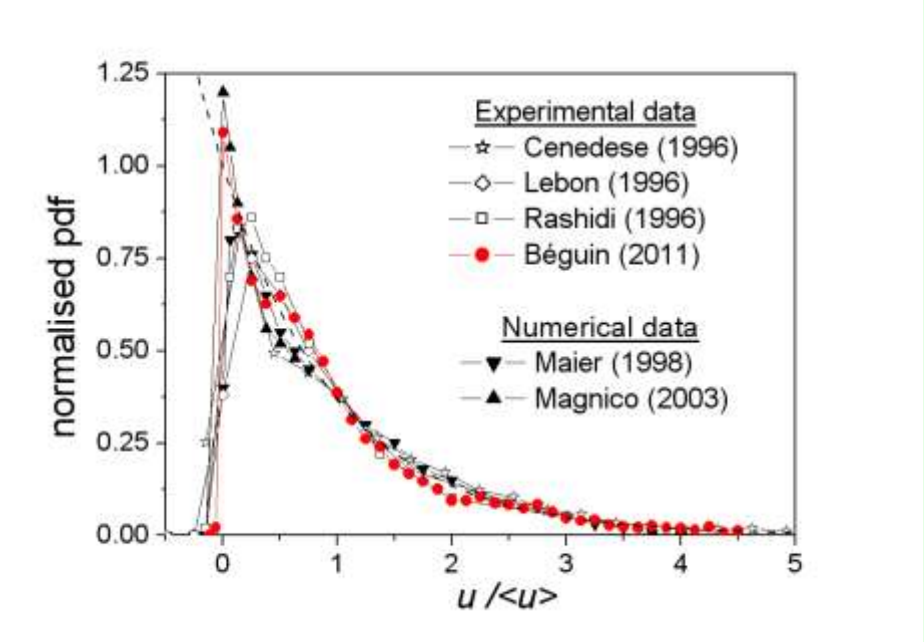
Statistical distribution of the velocities

Transverse component



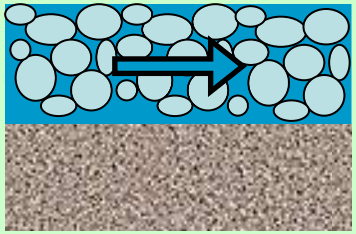
→ symetric and narrow distribution

Longitudinal component



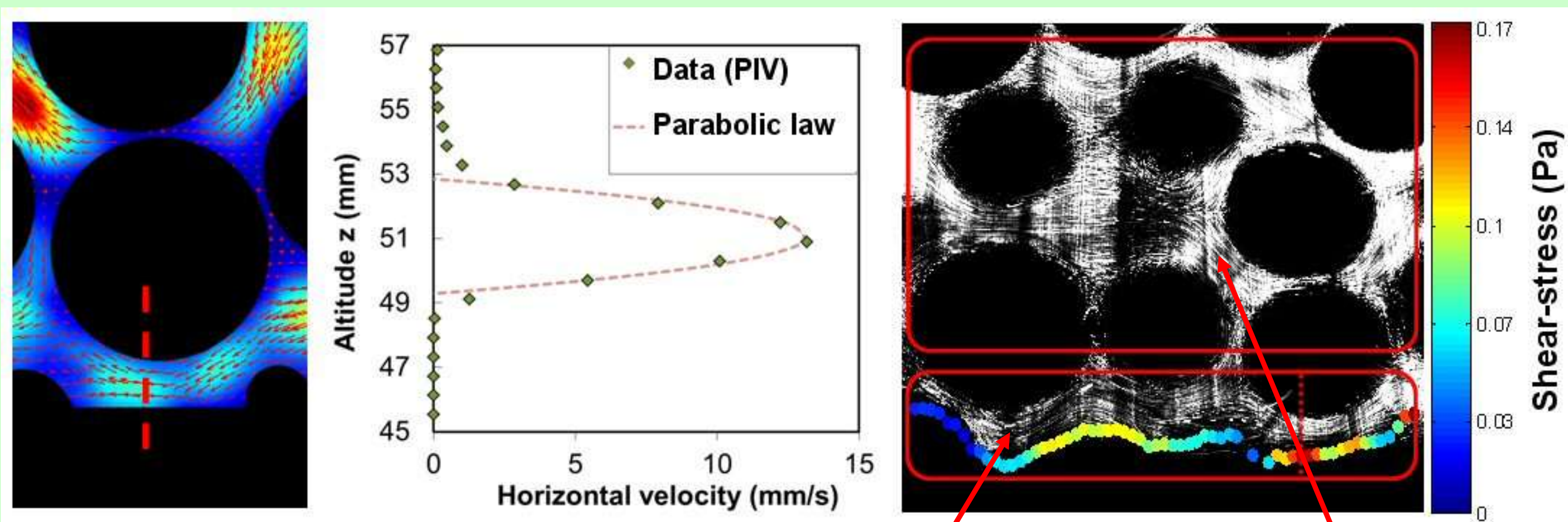
→ large tail distribution (log-normal/exponential)

Calculation of the shear stresses



Modelling of erosion → τ_b: bed shear stress at the fine soil surface (sand)

local erosion law: $$\varepsilon = \begin{cases} k_{er}(\tau - \tau_c) & \text{if } \tau > \tau_c \\ 0 & \text{else} \end{cases}$$



transition zone **bulk**