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The State of the Art and Science of Coastal Engineering

Shear stress measurements at the sea bottom by means of ferrofluids

DICAR

UNIVERSITÀ degli STUDI di CATANIA

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Motivation of the work

The direct measurement of wall shear stress is extremely important, since large flow resistances develop right at the boundaries. Present instruments used to this aim are:

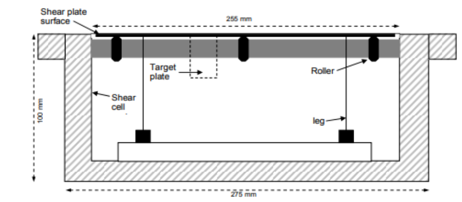
direct methods

- mechanical shear plates or cells (Riedel et al. 1972 , CENG)
- hot-film and hot-wire probes (Sumer et al. 1993, EiF)
- MEMS or bioluminescence (Foti et al., 2010, Meccanica)

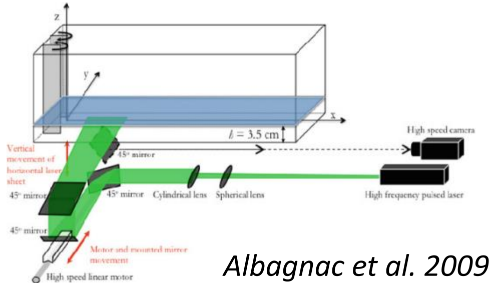
indirect methods

- acoustic and optical methodologies, such as ADV, LDA, PIV and PTV (Cox et al. 1996, JGR; Musumeci et al. 2006, JGR; Albagnac et al., 2009, EFM; Wallace and Vukoslavčević, 2010, ARFM)

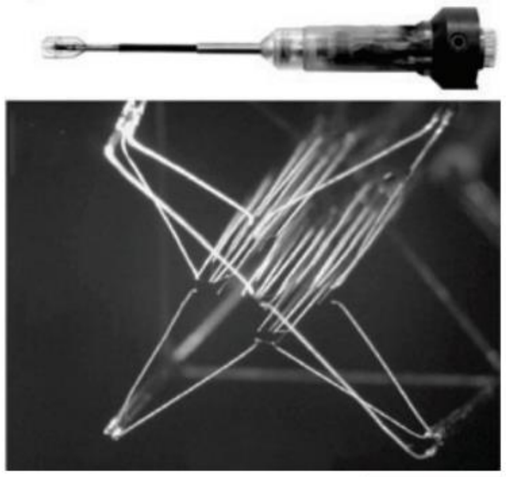
However, present instruments have pros and cons. In particular, the adoption in the presence of movable beds is extremely difficult.



Riedel et al. 1972

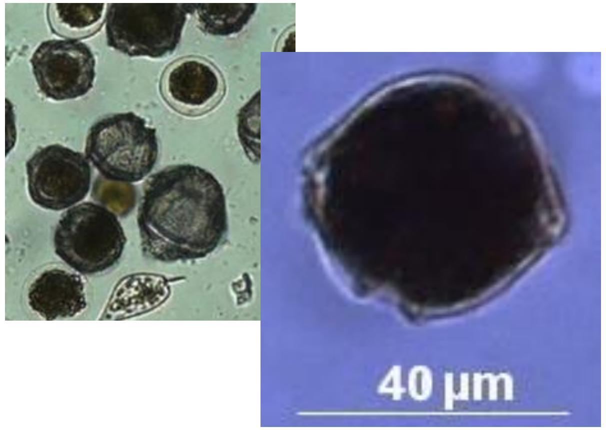


Albagnac et al. 2009



3 mm

Wallace et al. 2010



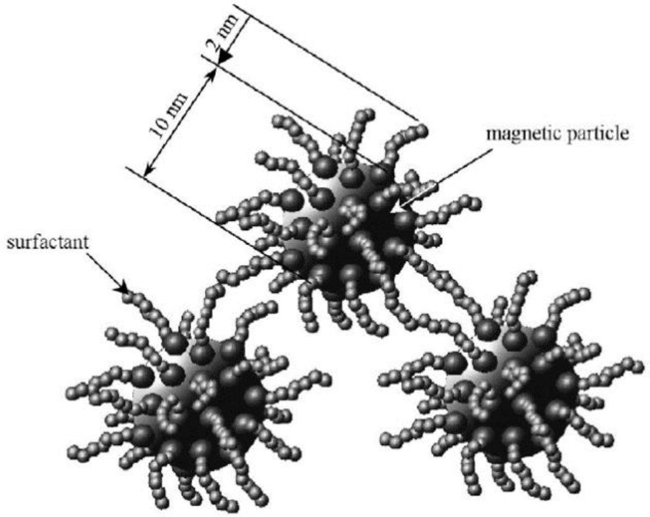
Foti et al. 2010

Ferrofluids

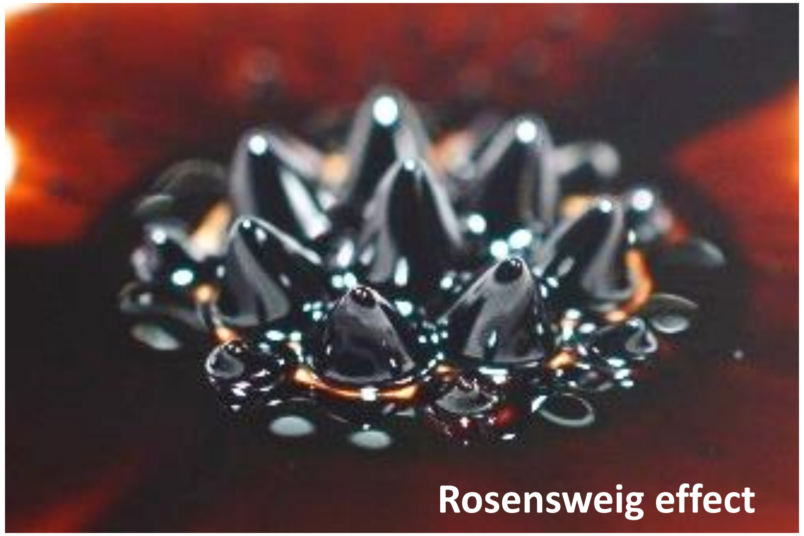
The ferrofluids are colloidal suspensions made up by nanoparticles of ferromagnetic materials (e.g. magnetite with size of about 10nm), dispersed in a non-magnetic solvent.

When they are exposed to an external permanent magnetic fields they form chan-like structures, oriented along the direction of the magnetic field (Rosensweig effect).

Ferrofluid structure (from Odenbach,2010)



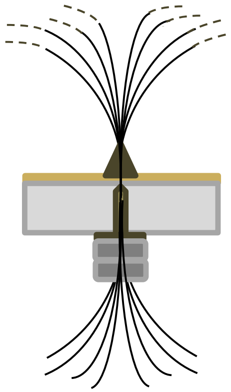
Magnetic control of the Rosensweig effect

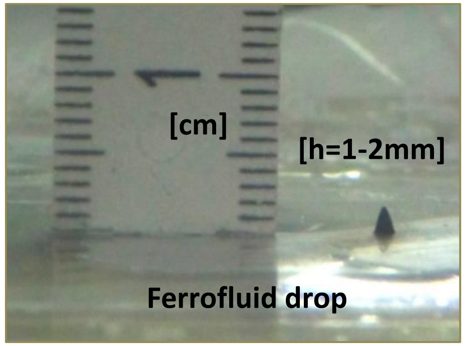


Rosensweig effect

The proposed measurement technique

The idea is to deploy the superparamagnetic properties of ferrofluids to develop a measurement technique able to measure shear stresses close movable bottoms by recording the deformation of the ferrofluid drop, whose height above the bottom is O(1mm) (Musumeci et al.2018).



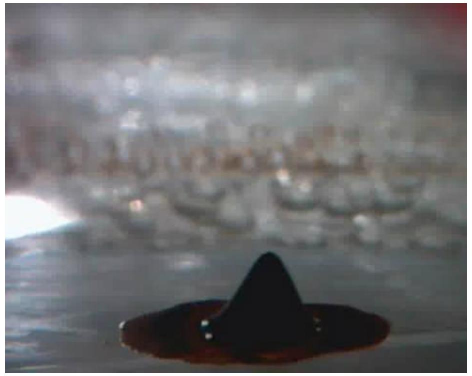


Principle of operation:

In the presence of a flow, a small quantity of ferrofluid (order of 0.01 milliliters) positioned at the wall and controlled by the action of a permanent magnetic field, will be deformed not only because of the applied magnets, but also due to the flow which acts on the ferrofluid drop.

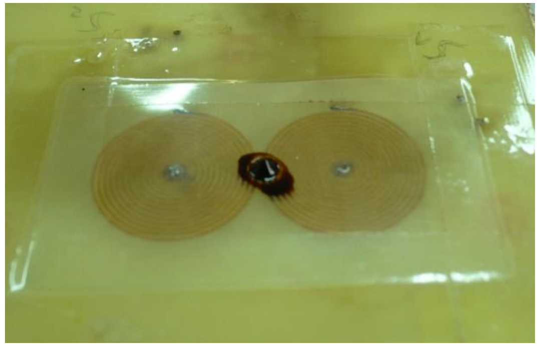
The problem is how to «sense» the ferrofluid deformation

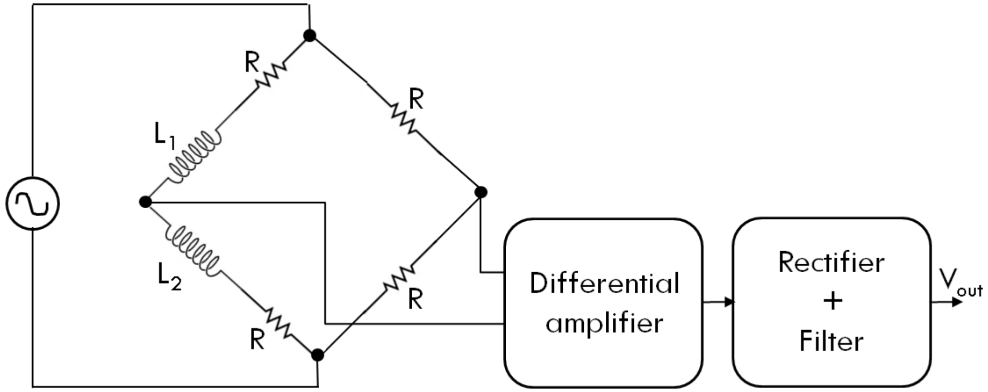
- Inductive readout strategy
- Optical readout strategy

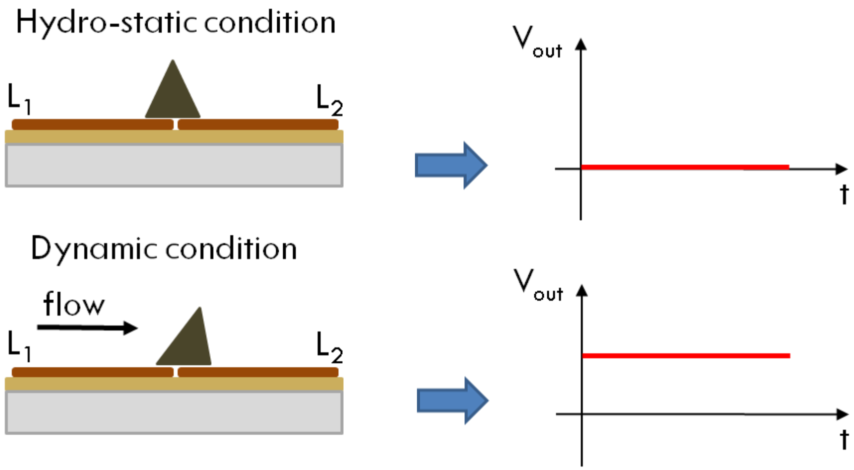


Inductive readout strategy

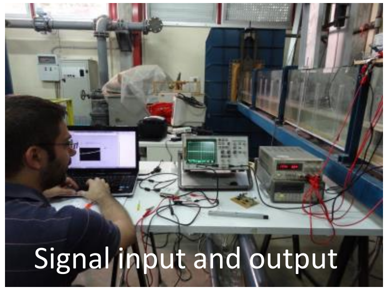
- The movement of the ferrofluid drop is sensed by two planar coils.
- The **perturbation of the magnetic field** generated by the movement of the ferrofluid drop is transduced into a voltage change by the conditioning circuit.

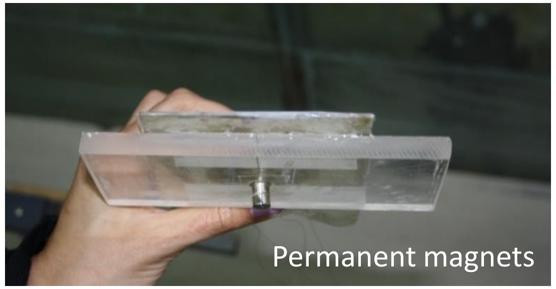






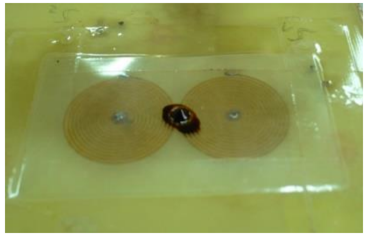

Ferrofluid drop above the coils


Signal input and output

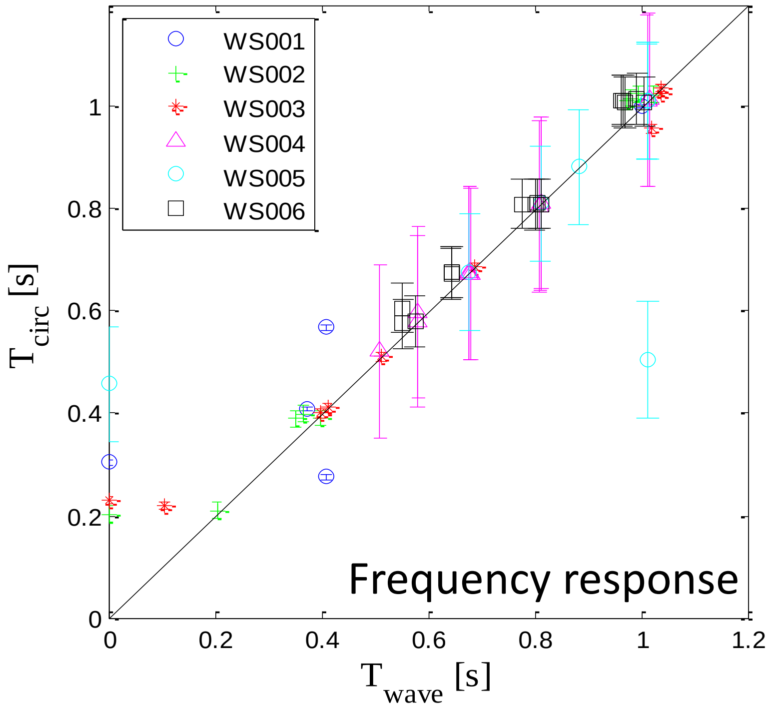

Permanent magnets

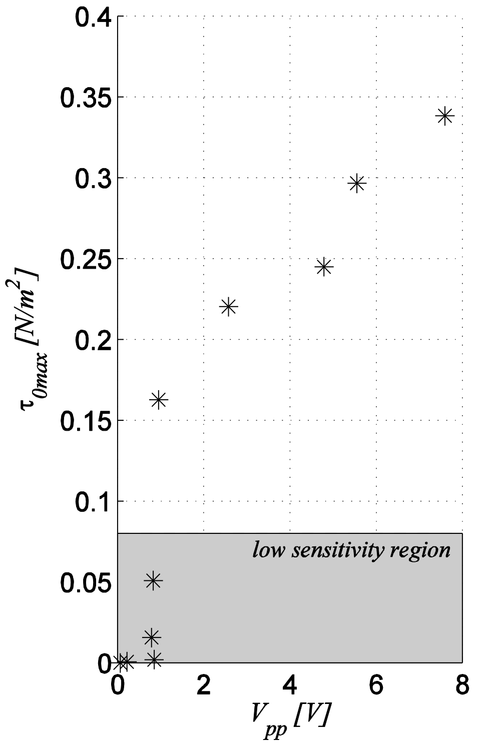

System over a sandy bottom

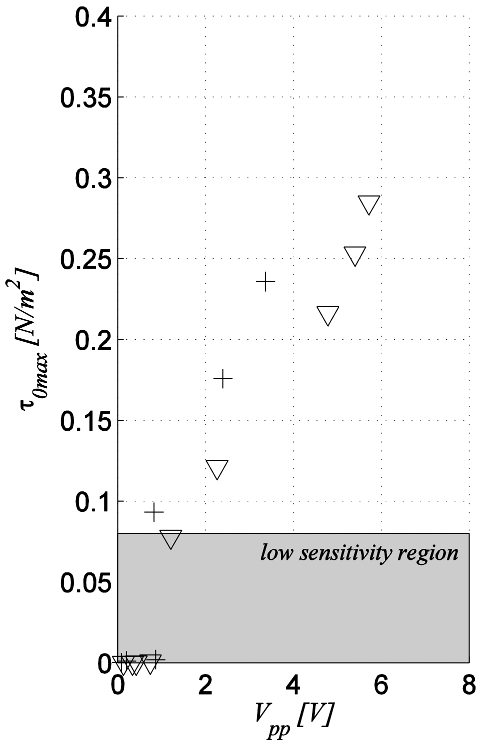
Inductive readout strategy



Calibration in the presence of regular surface waves







- A low sensitivity region of the conditioning circuit exists.
- The inductive strategy is a «blind» technique.
- What happens to the ferrofluidic sensor when the sediments impact on it?

Musumeci R.E., Marletta V., Sanchez-Arcilla A., Foti E. (2018) A ferrofluid-based sensor to measure bottom shear stresses under currents and waves. *Journal of Hydraulic Research*.

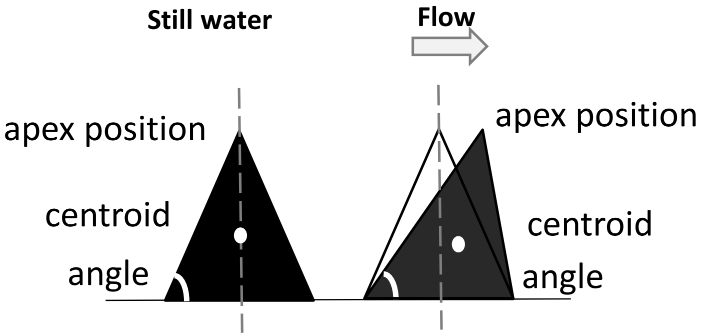
Optical readout strategy

Goals of the work

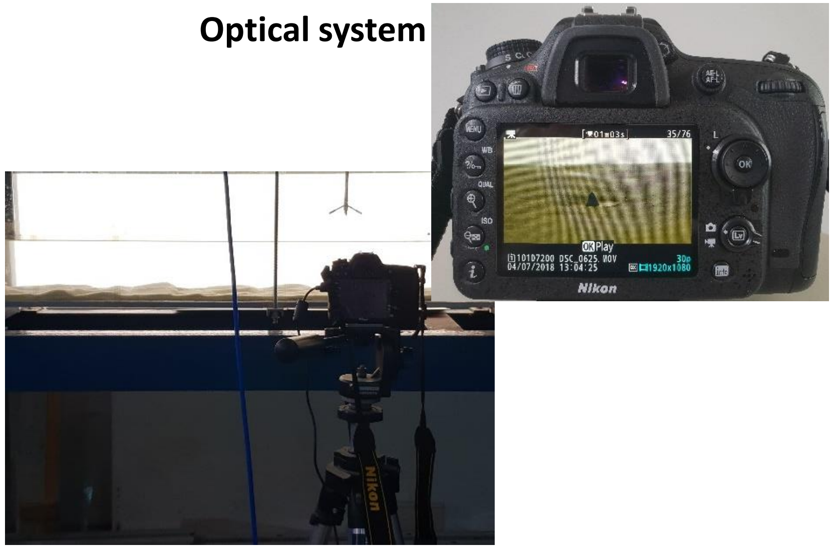
- Analysis on the **parameters** useful to describe the **drop deformation**

- **Assessment** of the **optical system** in the presence of different movable bottom conditions

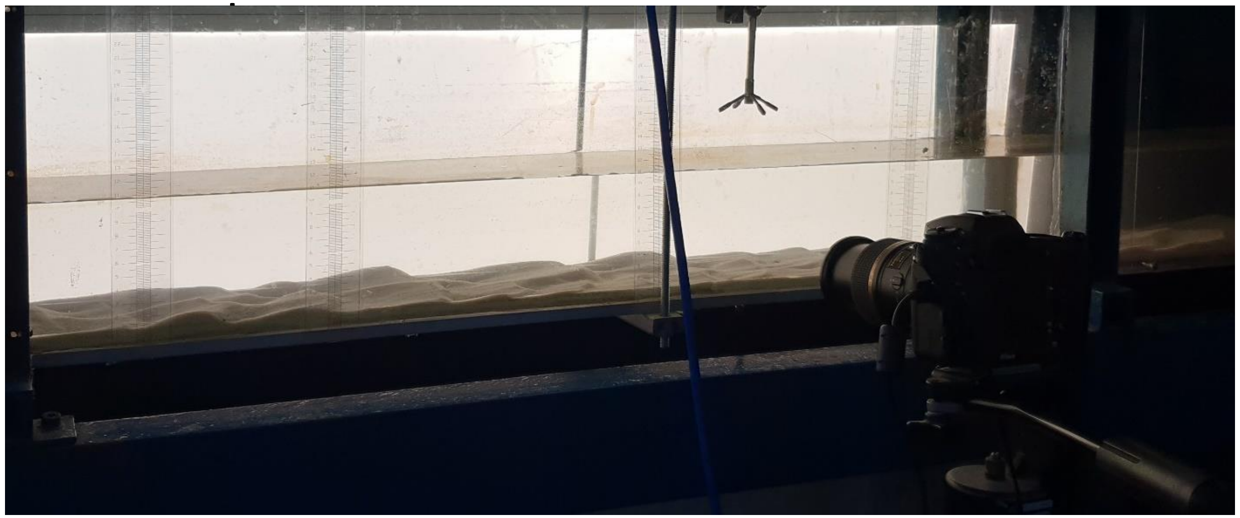
Optical parameters to recover drop deformation :



Optical system



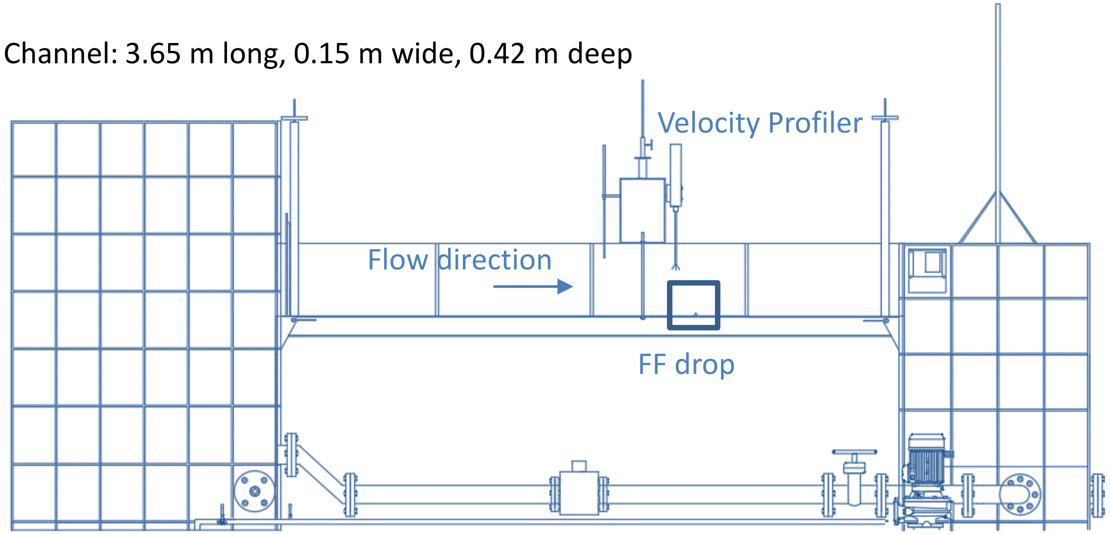
Proposed measurement technique on sandy bottoms



Experimental apparatus

Steady current hydraulic flume at the Hydraulic Laboratory of the University of Catania:

Channel: 3.65 m long, 0.15 m wide, 0.42 m deep



- **Ferrofluid spike formation**

Fixed volume pipette

Permanent magnets

Ferrofluid

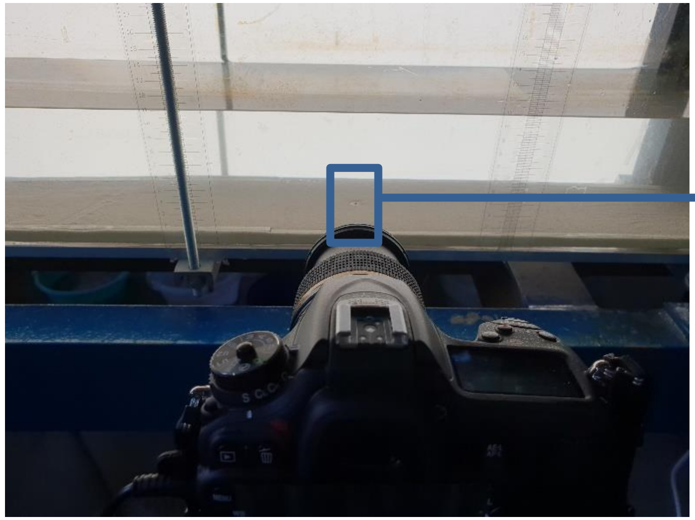
- **Flow velocity**

Vectrino Profiler

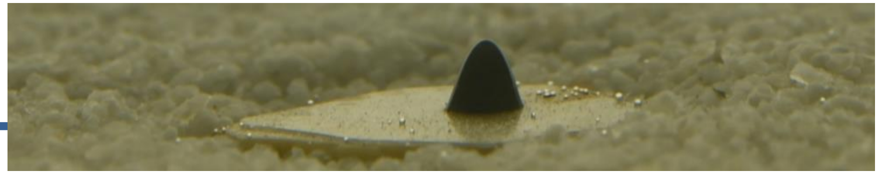
- **Optical readout tools**

NikonD7200

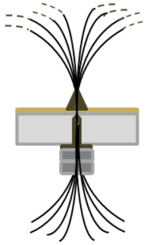
Tamron AF 90 mmm f 1:2.8 Macro 1:1



Layer of sediments thickness of about 5 mm



Ferrofluid located on a small cylinder (ϕ=1,4 cm) , to control its position on the sandy bottom



Experiments

Steady current tests over:

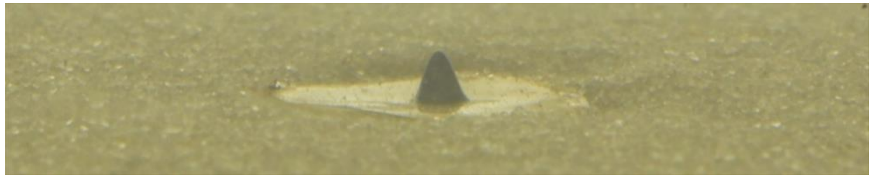
- ➢ uniform sandy bottoms
  - ▪ **2** different **uniform sands** (fine and coarse sand)
  - ▪ **15** different **hydraulic conditions** (v_∞=0-35 cm/s)
- ➢ sandy bottom made up by binary mixtures
  - ▪ **4** different **sediment mixtures**
  - ▪ **15** different **hydraulic conditions** (v_∞=0-35 cm/s)

Volumetric concentration of sediments

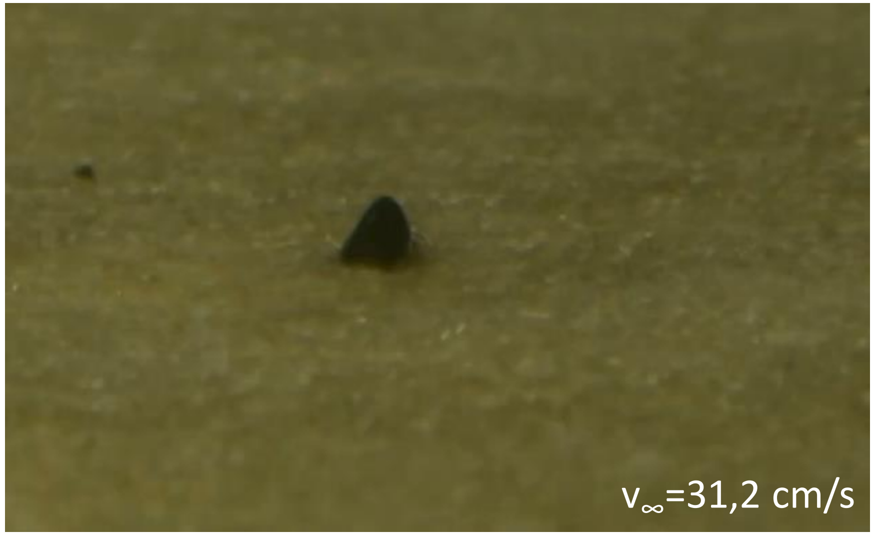
fine sand	coarse sand
100%	-
-	100%
90%	10%
80%	20%
70%	30%
60%	40%

fine sand d_{50} = 0.25 mm
coarse sand d_{50} = 0.56 mm

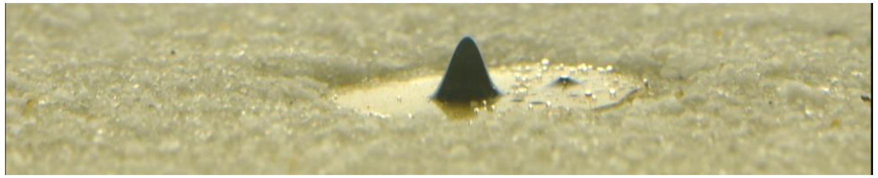
Uniform: fine sand



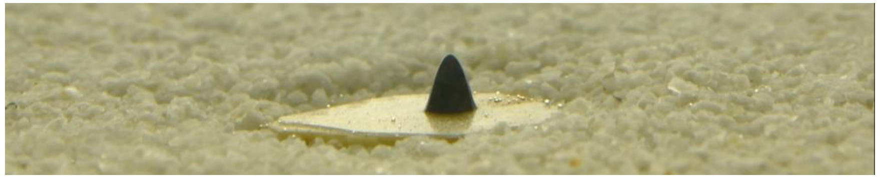
Mixture: 90% fine sand – 10% coarse sand



Mixture: 70% fine sand – 30% coarse sand



Uniform: coarse sand

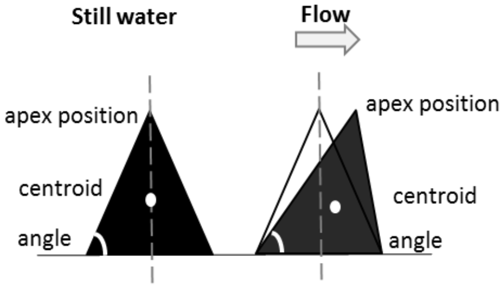


FF volume 5 μl

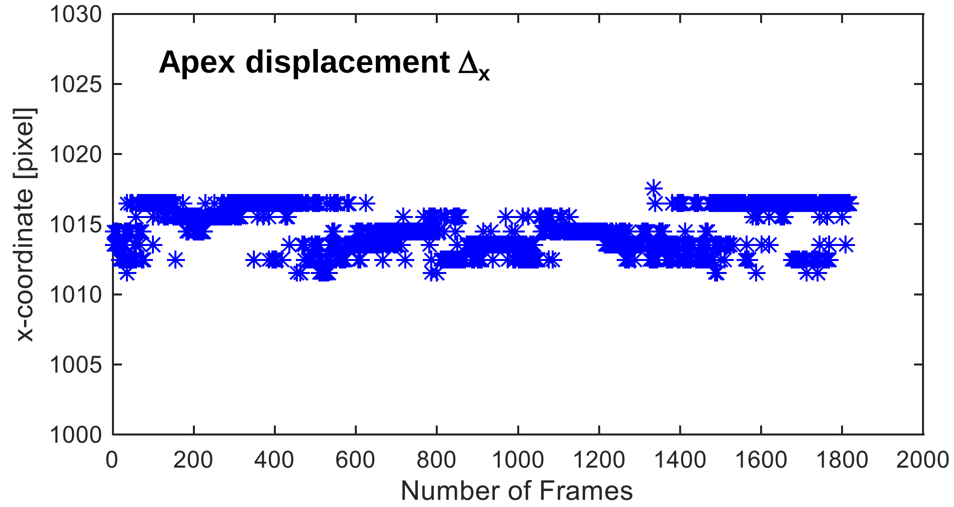
Magnetization strength
6 magnets x 11.8 N + 6 magnets x 22.5 N

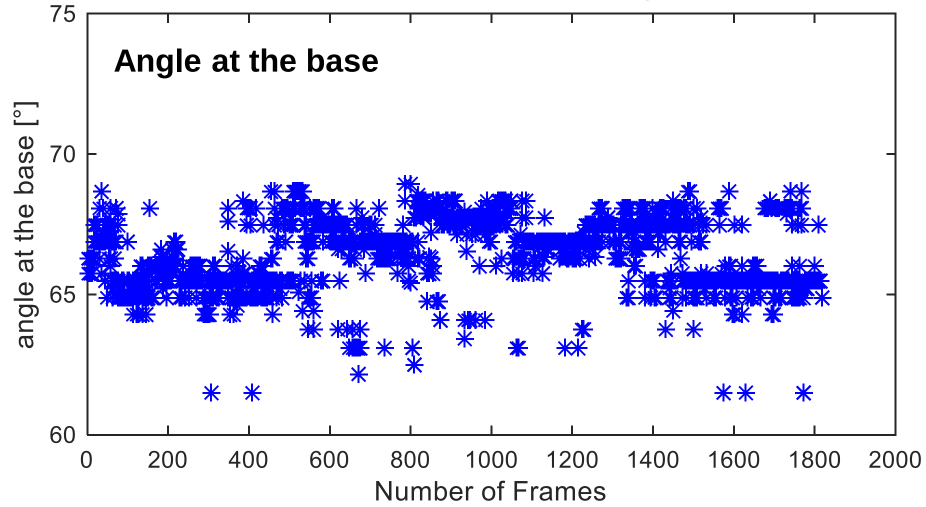
Preliminary analysis on the drop deformation

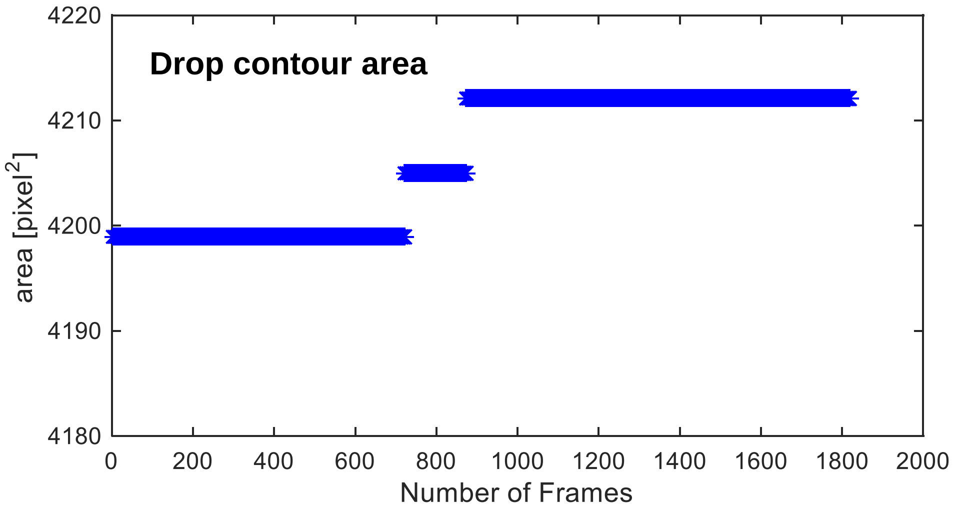
Bottom: 60% fine sand-40% coarse sand - V_∞ = 4.5 cm/s

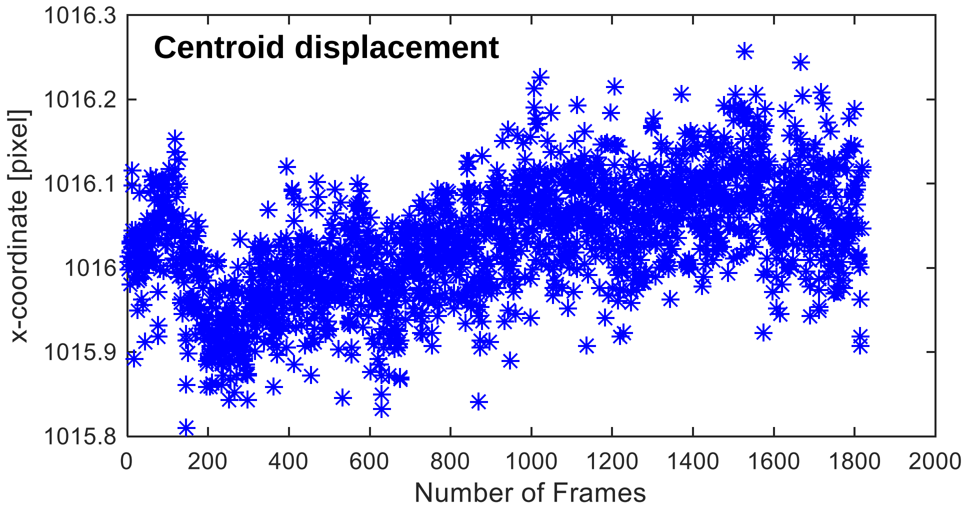


Over sandy bottom





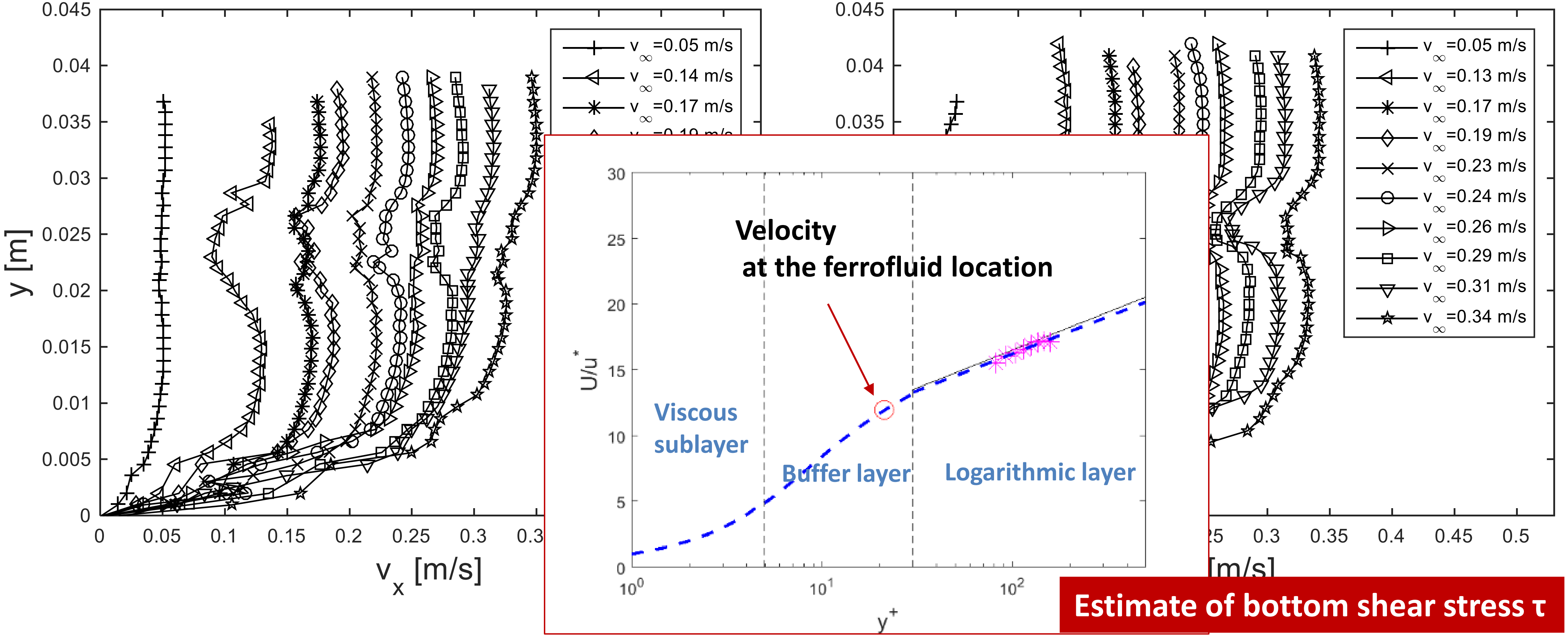




Evaluation of the hydrodynamic conditions

TIME-AVERAGED VELOCITY PROFILES

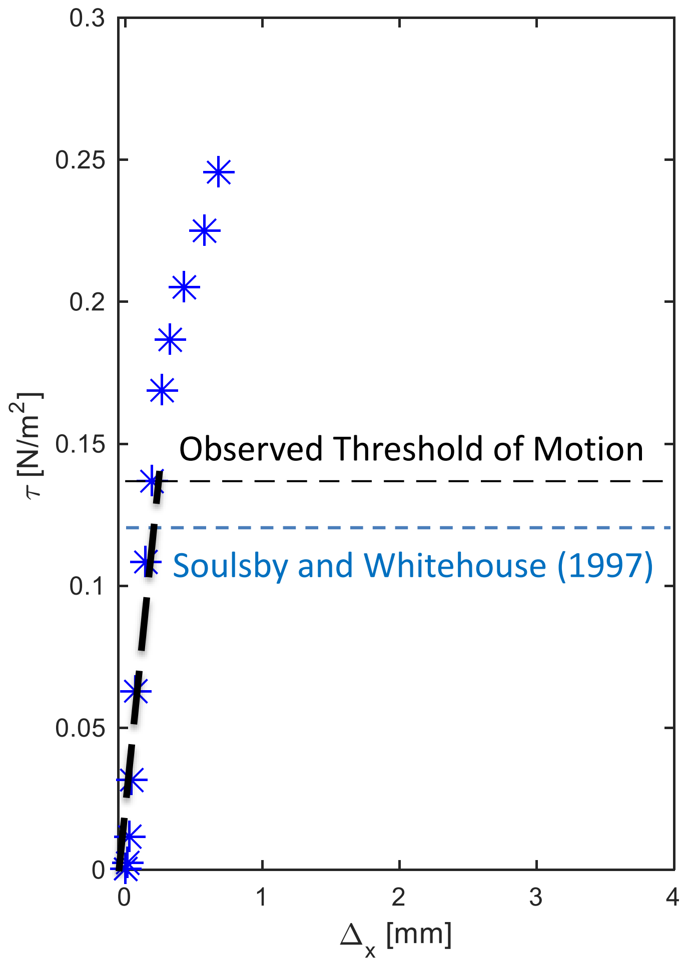
Bottom: 100% coarse sand | **Bottom: 70% fine sand-30% coarse sand**



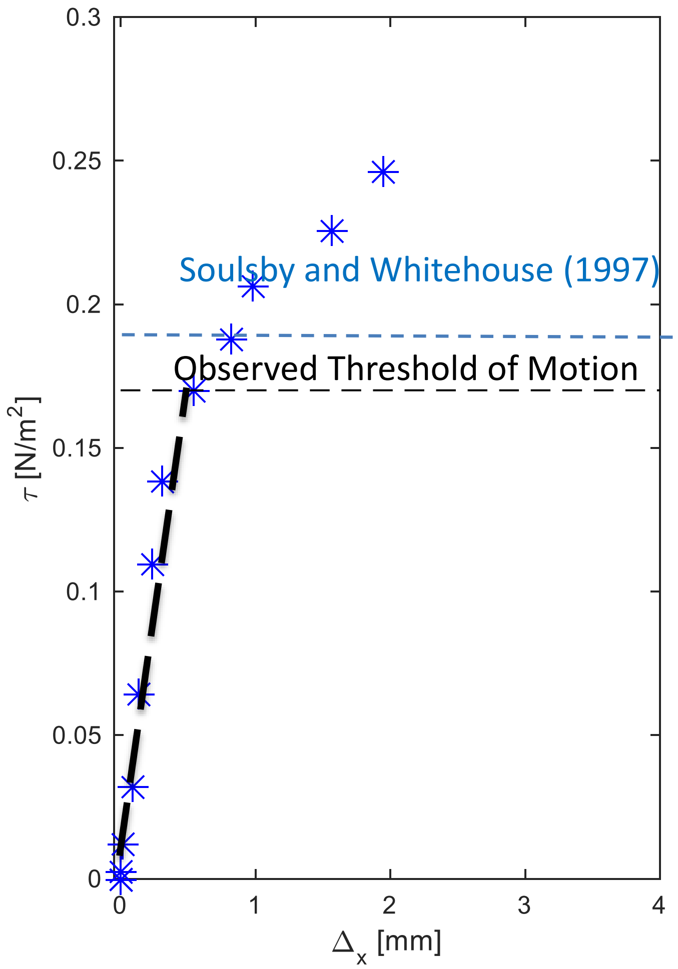
Estimate of bottom shear stress τ

Relationship between τ and FF Δ_x : uniform sand

Bottom: 100% fine sand



Bottom: 100% coarse sand



At ToM:

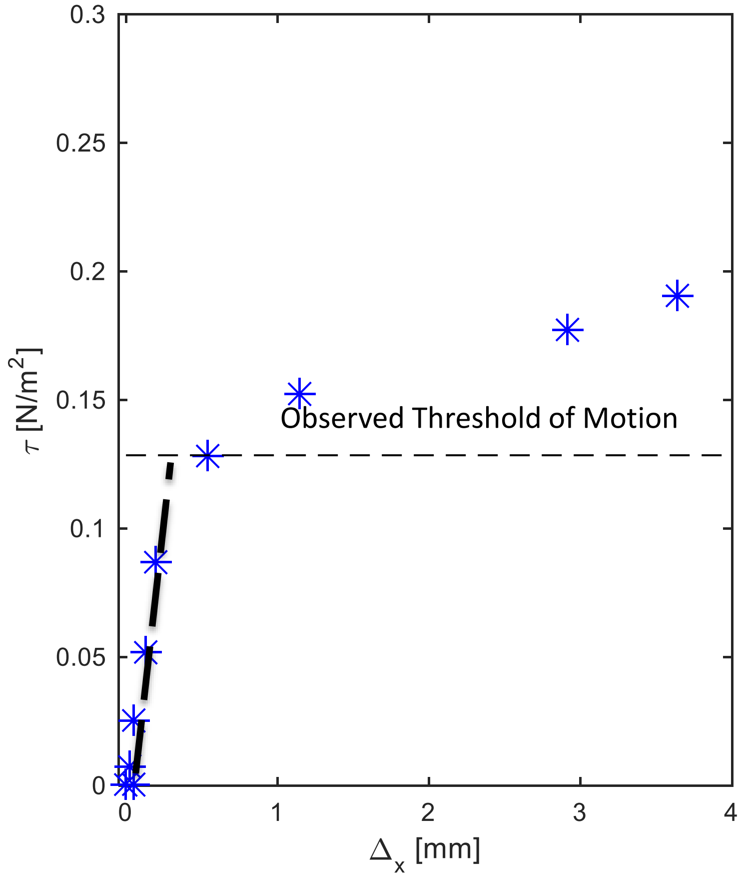
- Change of slope

From fine to coarse sand:

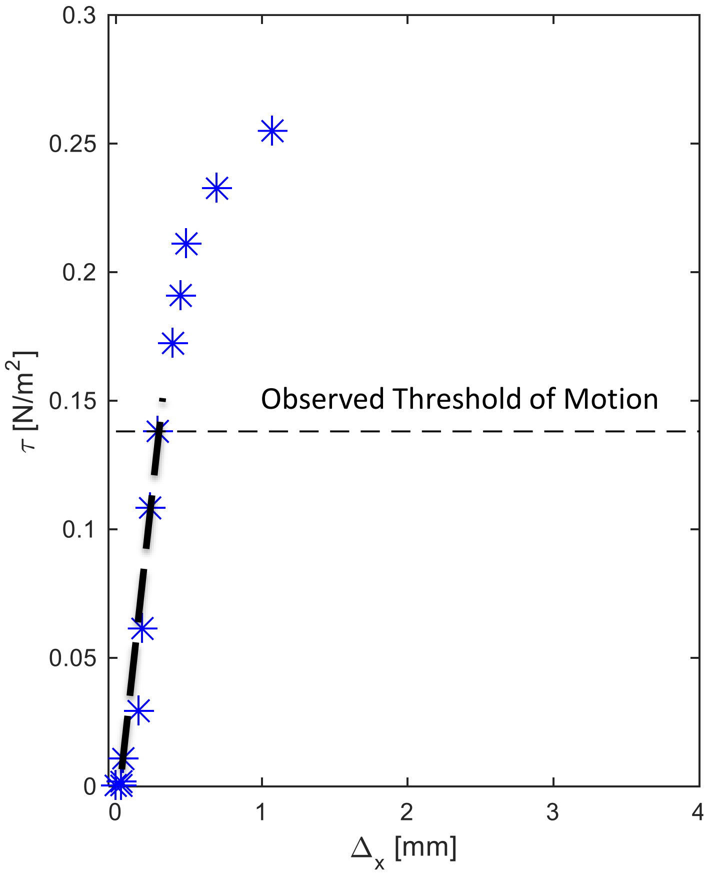
- Increase of ToM
- Sensitivity to bottom roughness

Relationship between τ and FF Δ_x : binary mixture

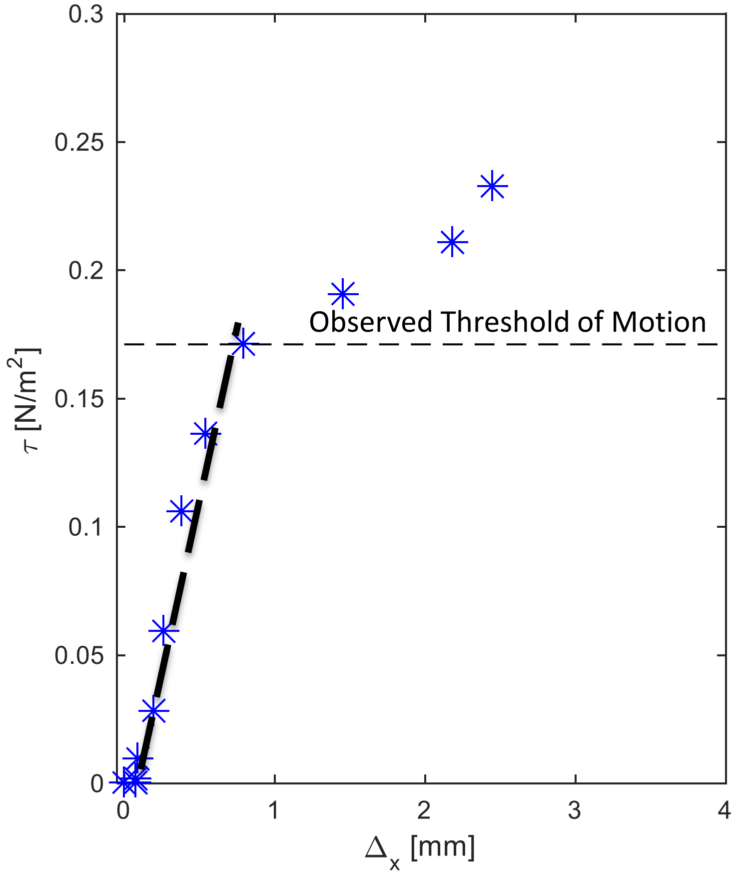
80% fine sand - 20% coarse sand



70% fine sand - 30% coarse sand

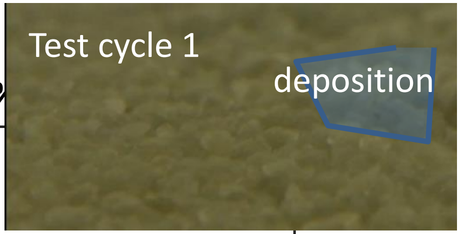


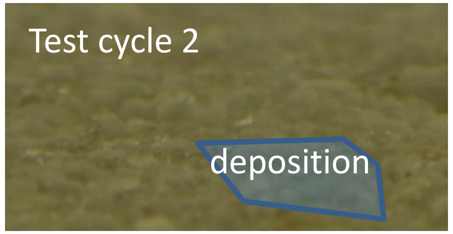
60% fine sand - 40% coarse sand

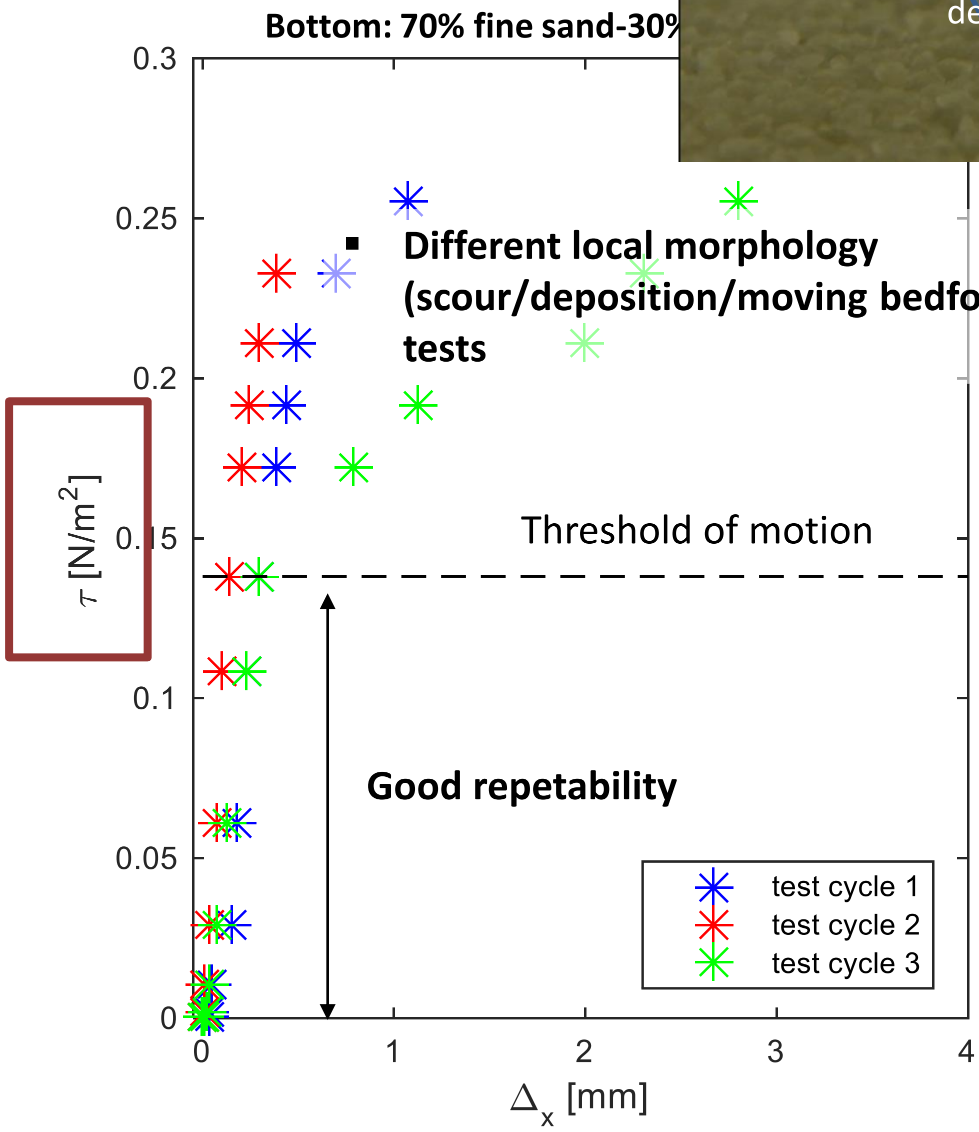


- Coherent behavior below ToM
- Doubtful (linear?) behavior above ToM

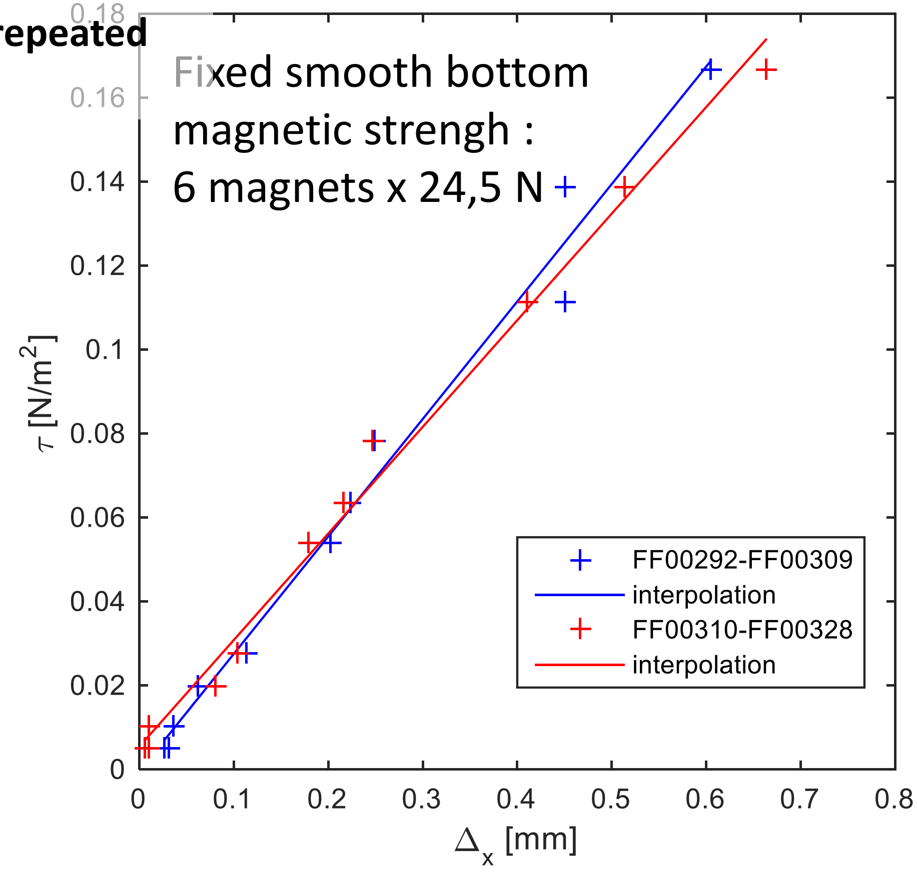
Analysis of results







- **Different local morphology (scour/deposition/moving bedforms) in repeated tests**



Conclusions

- A novel technique for the measurement of the wall shear stress based on ferrofluids is proposed
- An experimental campaign is carried out in the presence of sandy bottoms: uniform and binary mixtures
- The FF sensor shows a linear behavior and:
  - it is able to measure the shear stress changes induced by the difference of bed roughness
  - it shows a coherent behavior below ToM/automatically detect the ToM
- More work is needed in order to
  - quantitatively calibrate the FF sensor above the ToM
  - compare the inductive readout strategy and the optical one to provide a more robust methodology which can be used both at small scale and at large scale facilities

Acknowledgements: hydralab+