Laboratory meter-scale seismic monitoring of varying water levels in granular media

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Laboratory physical modeling and non-contacting ultrasonic techniques are frequently proposed to tackle theoretical and methodological issues related to geophysical prospecting. Following recent developments illustrating the ability of seismic methods to image spatial and/or temporal variations of water content in the vadose zone, we developed a laboratory experiment aimed at testing the sensitivity of seismic measurements (*i.e.*, pressure-wave travel times and surface-wave phase velocities) to water saturation variations. Ultrasonic techniques were used to simulate typical seismic acquisitions on small-scale controlled granular media presenting different water levels. Travel times and phase velocity measurements obtained at the dry state were validated with both theoretical models and numerical simulations and serve as reference datasets. We then studied the differences in travel time and phase velocity observed between the dry and wet models to estimate the thicknesses of the fully, partially, and unsaturated areas of the granular medium.

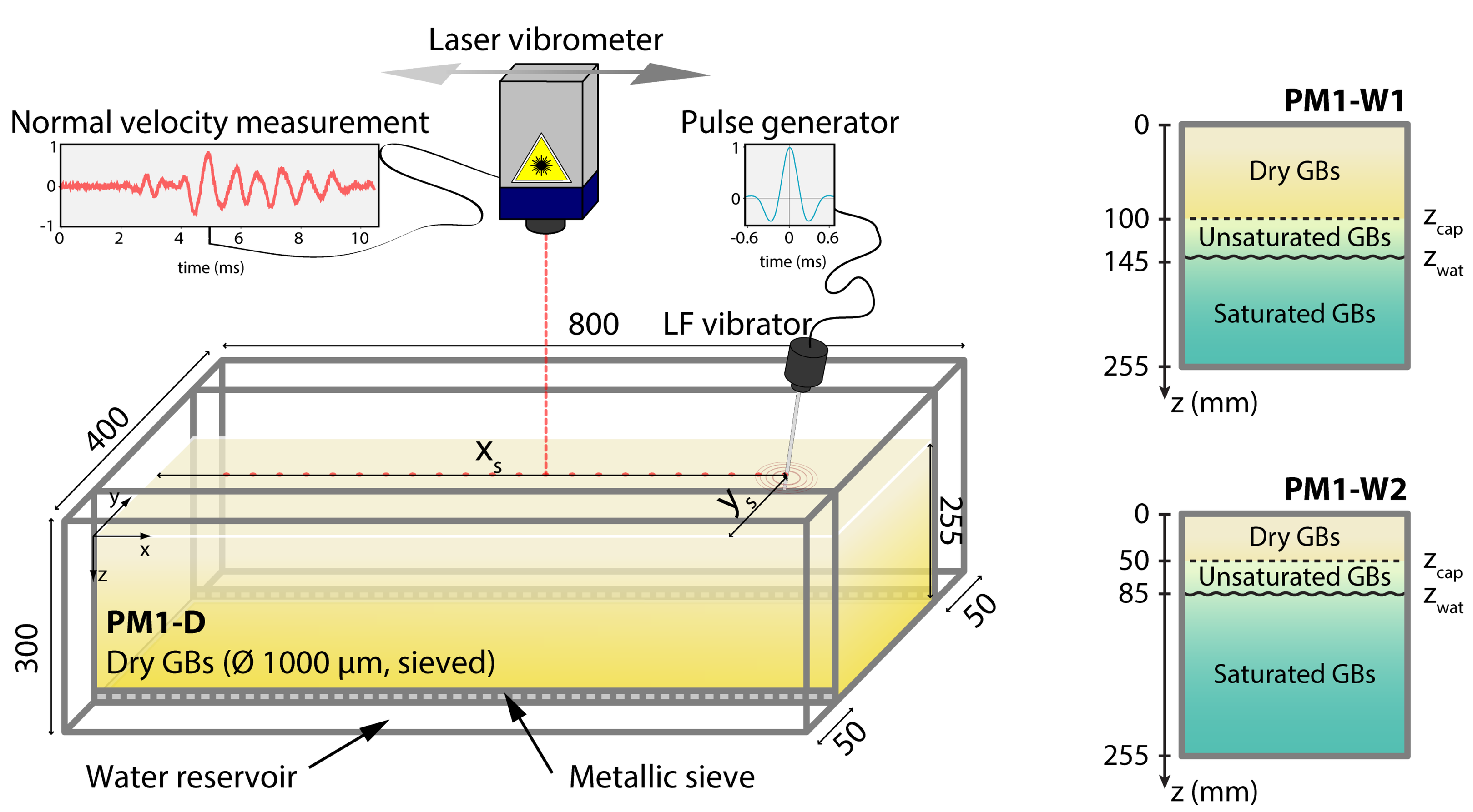
1 Experimental setup and data acquisition

Setup adapted from Bodet *et al.* (2014) to handle **wet conditions**

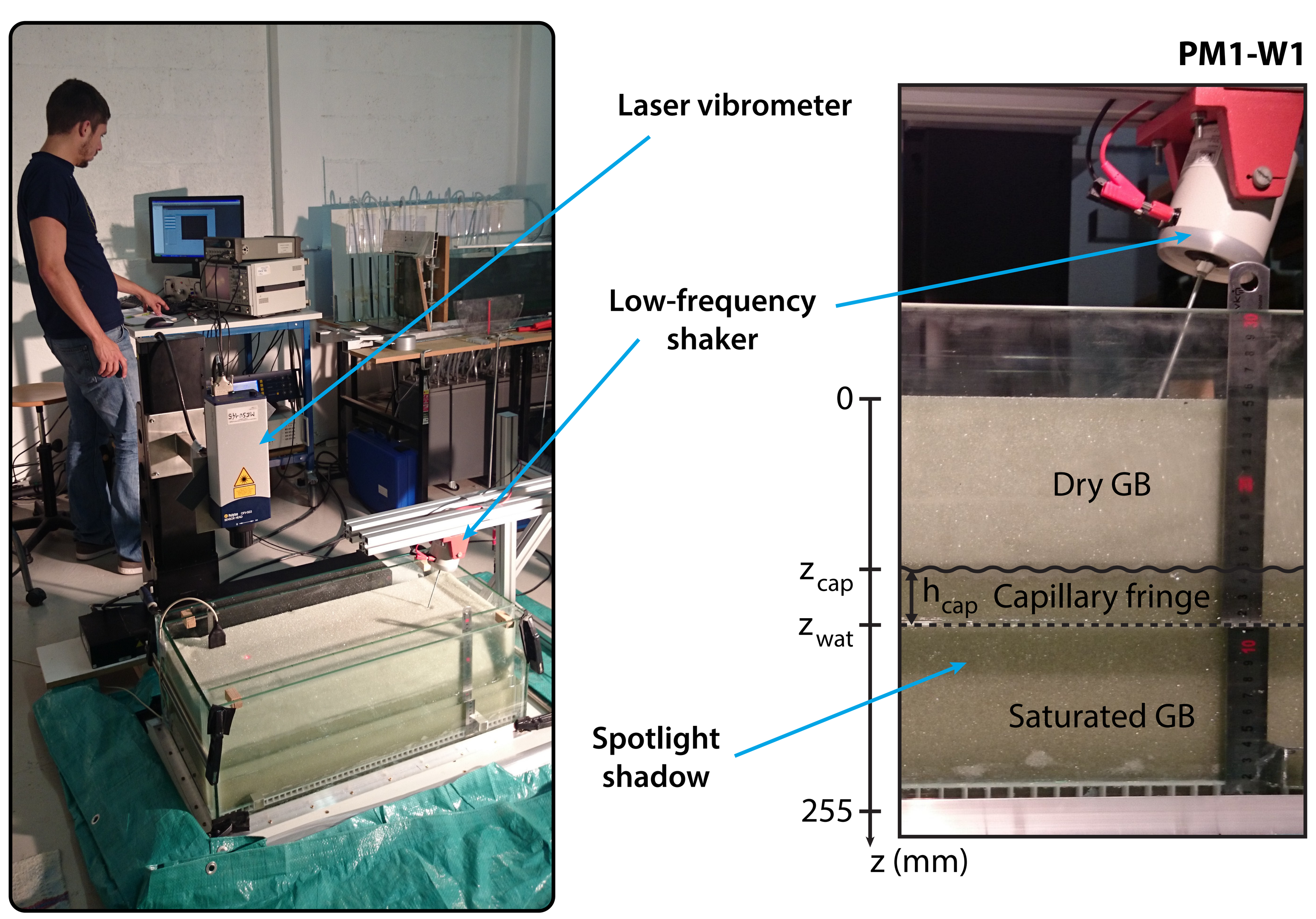
=> glass tank filled w/ **1000 µm diameter glass beads**

=> measurements at **dry state** and at **two water levels**

=> seismogram w/ fixed **low-freq. shaker** and moving **laser vibrometer**



Dimensions in mm (not to scale)



2 Dry and wet models characterization

Typical wavefield events identified on the seismograms

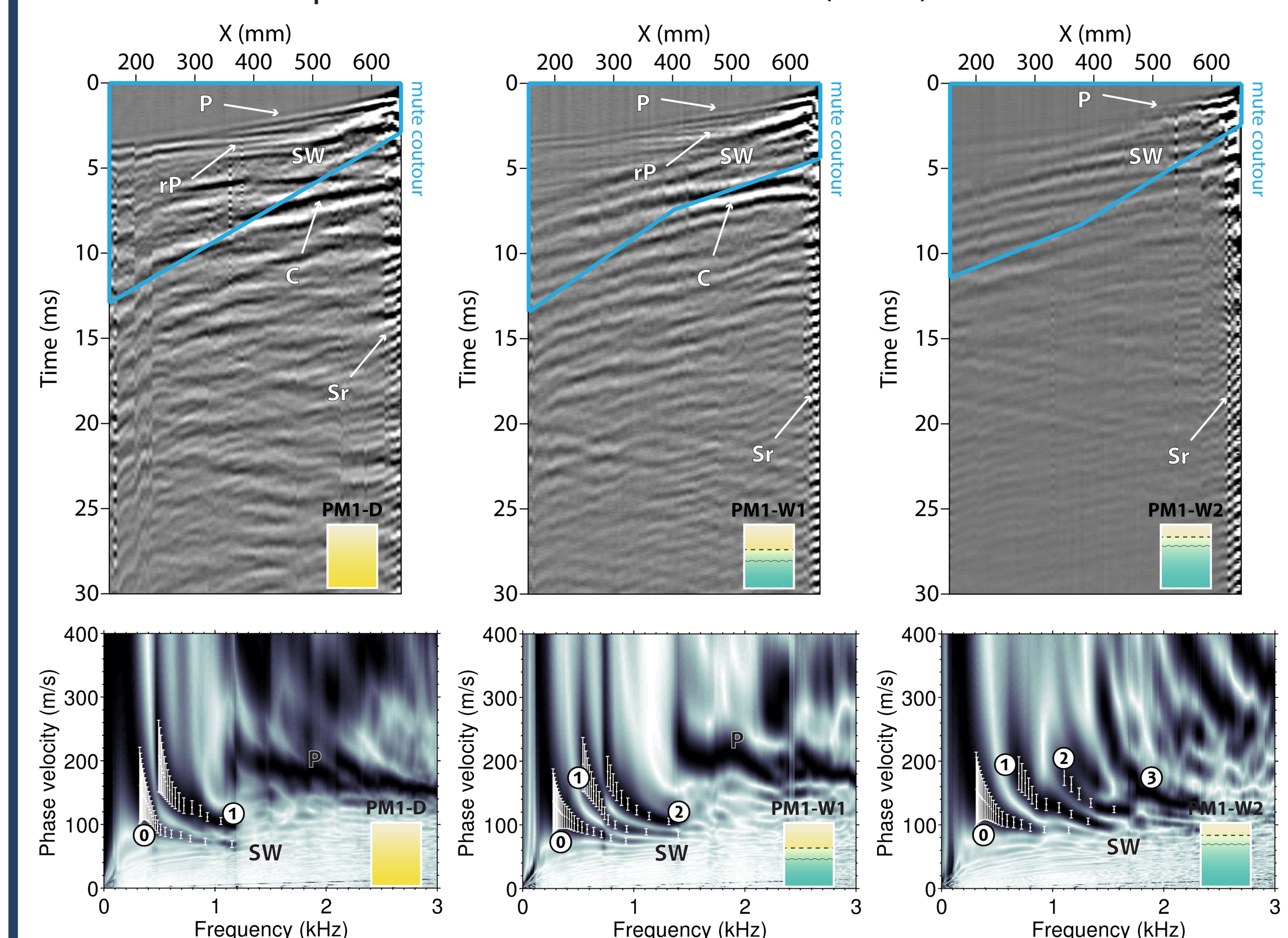
=> pressure waves (P) and surface waves (SW)

=> bottom reflections (rP) and converted waves (C)

=> source ringing (Sr)

Wavefield transform (Mokhtar *et al.*, 1988) to identify SW dispersion

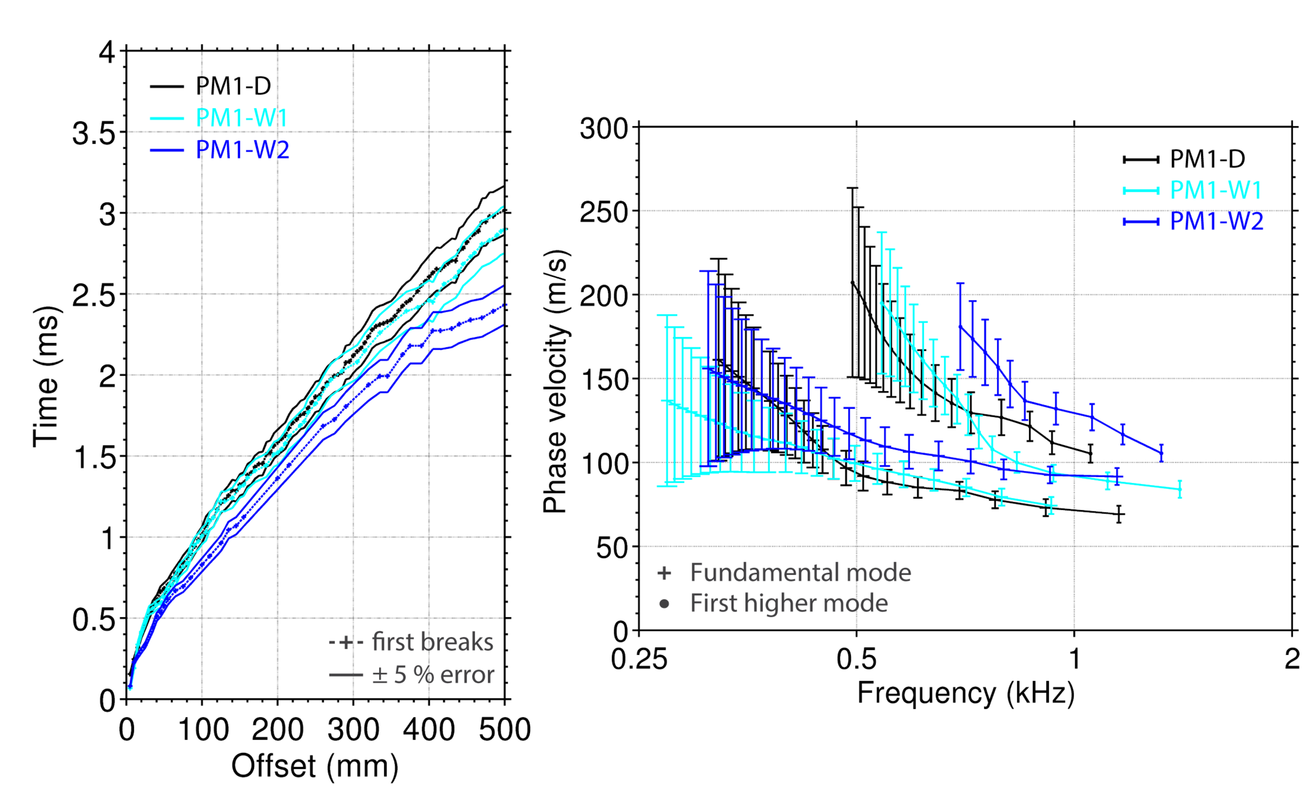
=> separation of **different SW modes** (0 to 3)



Data comparison of wet models with dry reference

=> **shorter traveltimes** for both water levels (3 distinct slopes for PM1-W2)

=> overall trend of **increasing phase velocity** for PM1-W2



3 Timelapse data differences

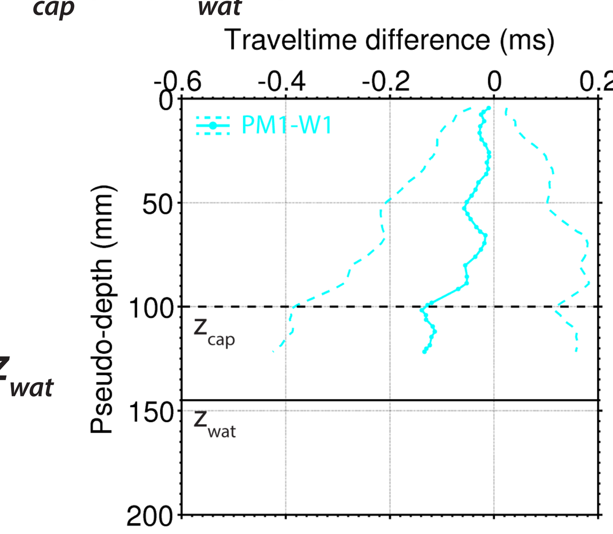
Traveltime differences

=> moving window along offset axis

=> pseudo-depth estimated from max. ray depth in dry medium

=> no significant trend for PM1-W1

=> **inflection points consistent with z_{cap} and z_{wat} for PM1-W2**



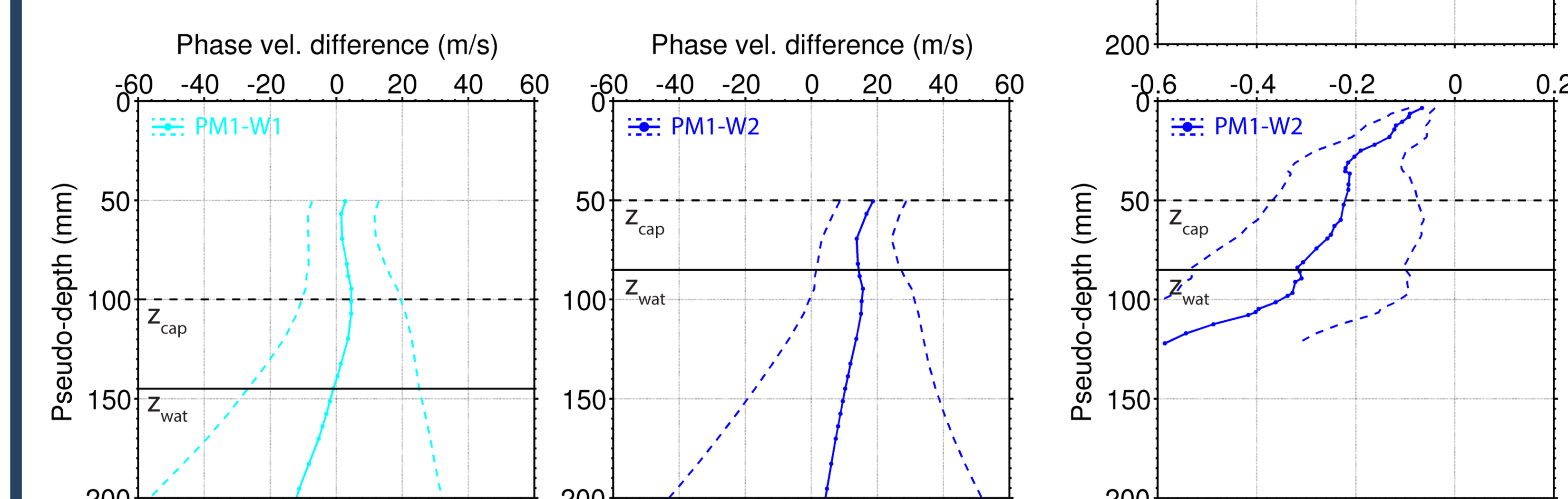
Phase velocity differences

=> moving window along frequency axis

=> pseudo-depth estimated from wavelength ($z = 0.63\lambda$, Xia *et al.*, 1999)

=> no significant trend for PM1-W1

=> **inflection points consistent with z_{cap} and z_{wat} for PM1-W2** (though less obvious)



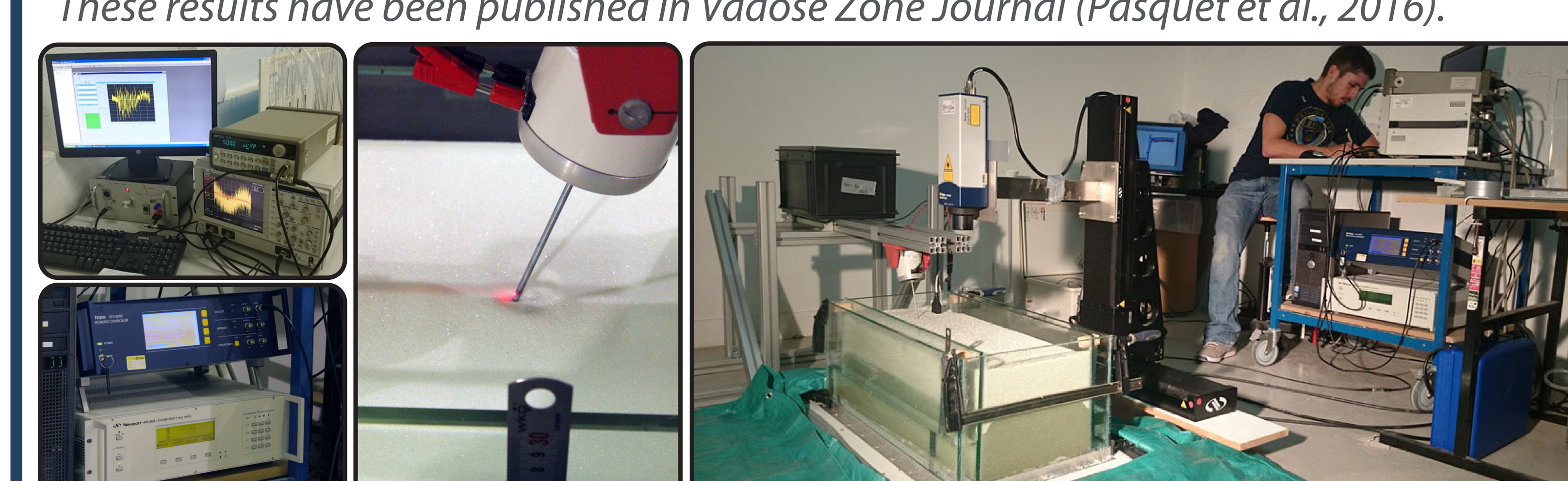
4 Conclusions

The results of laser-Doppler experiments performed on unconsolidated granular media with different water levels show:

- **clear influence of the increasing water table on the recorded wavefield** (P traveltimes, SW phase velocities and overall amplitude)
- **differences in traveltime and phase velocity** between dry and wet models show patterns that **match the water level and depth of the capillary fringe**

Approach recently applied for **timelapse monitoring of vadose zone water** (Pasquet *et al.*, 2015; Bergamo *et al.*, 2016a,b; Dangeard *et al.*, 2016)

These results have been published in Vadose Zone Journal (Pasquet et al., 2016).



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