Sensitivity of seismic-noise based methods to controlled water content changes: insight from laboratory measurements

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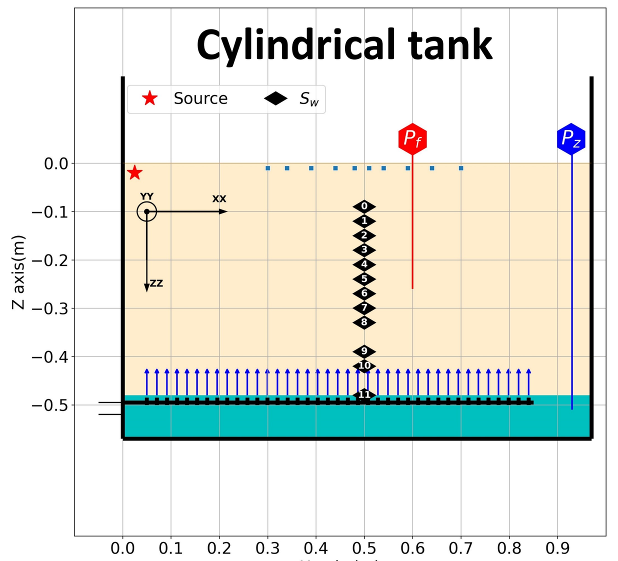
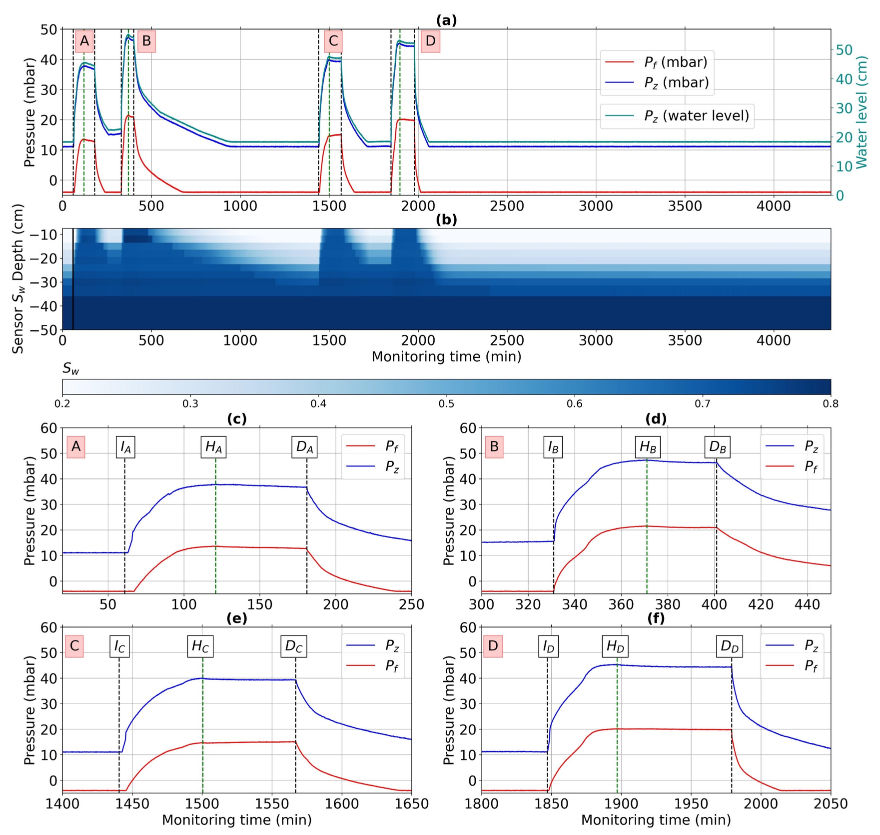
Aim of the study

In recent years, seismic-noise based methods have shown great potential for the monitoring of various processes occurring in the Earth's crust. Among them, the fine detection of hydrological variations at different scales is a major issue in the context of water resources management. In order to better understand the sensitivity of continuous seismic wavefields to water content variations affecting both saturated and unsaturated zones, we have set up a dynamic and meter-scale laboratory experiment. This sandbox experiment reproduces field surveys based on the recording and processing of seismic background noise (hundred to kiloHertz range) in the context of hydrological variations. These multiple measurements, which benefit from independent measurements of pressure and water saturation at different depths, allow us to refine the sensitivity of the seismic wavefield to variations in water content and hysteretic behavior related to different phases of imbibition/drainage.

The experimental setup





Landes sand $\phi \sim 0.4, k_0 \sim 10^{-12} m^2$

10 -3C Accelerometers

2 Pressure sensors

12 Saturation probes

1 piezoelectric loudspeaker

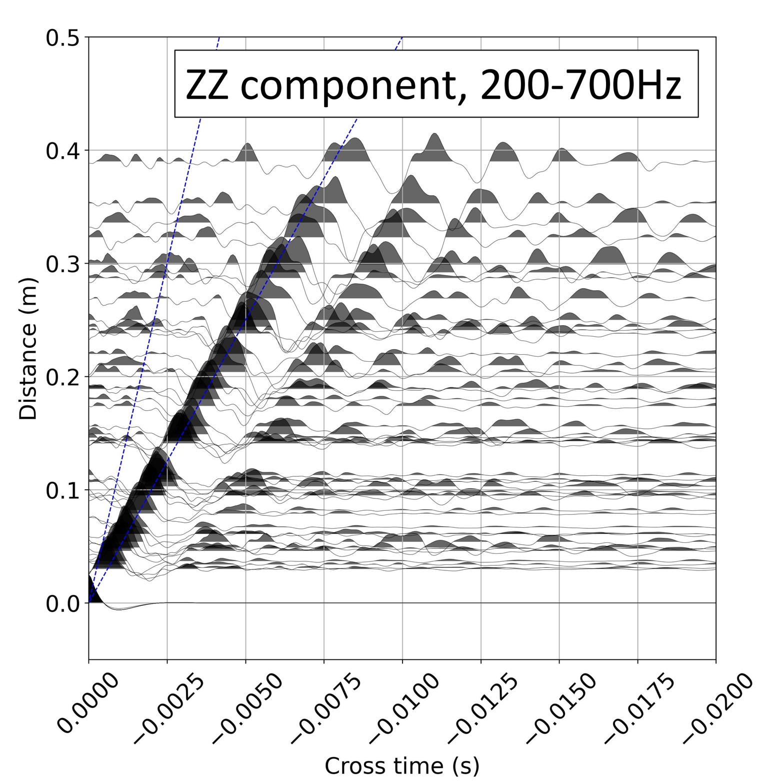
Seismic noise is continuously emitted and recorded during 4 imbibition/drainage cycles (72h)

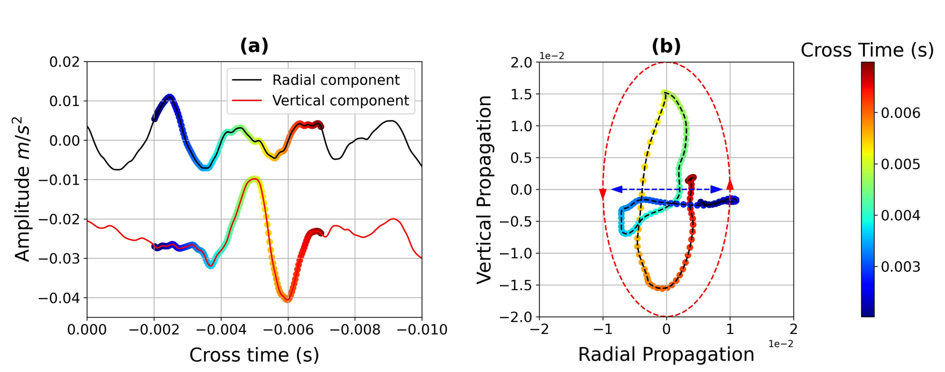
Wavefield recovery and identification

From the recording of the seismic noise on the accelerometer array, we obtain a set of **45 pairs of receivers with various distances.**

Seismograms are recovered from the crosscorrelations after whitenning and filtering.

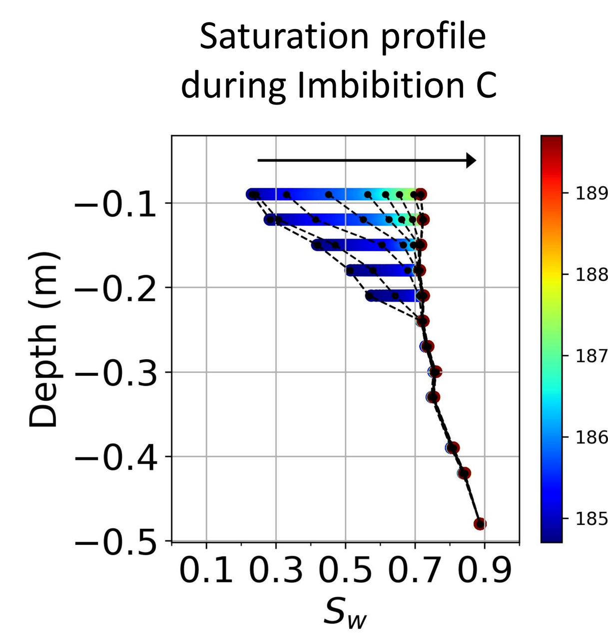
A clear wave propagates with a 60 m/s velocity (low saturation)



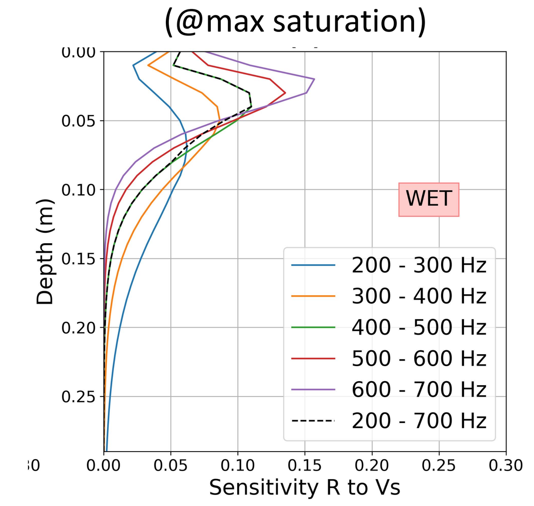


Both apparent velocity and polarization confirm the wavefront to be associated to **Rayleigh waves**

Sensitivity kernels



Sensitivity kernels show the Rayleigh wave **to be very sensitive to the first 15cm *i.e.* to the vadose zone**



Computed for a constant phase velocities VP=114m/s and VS=65m/s

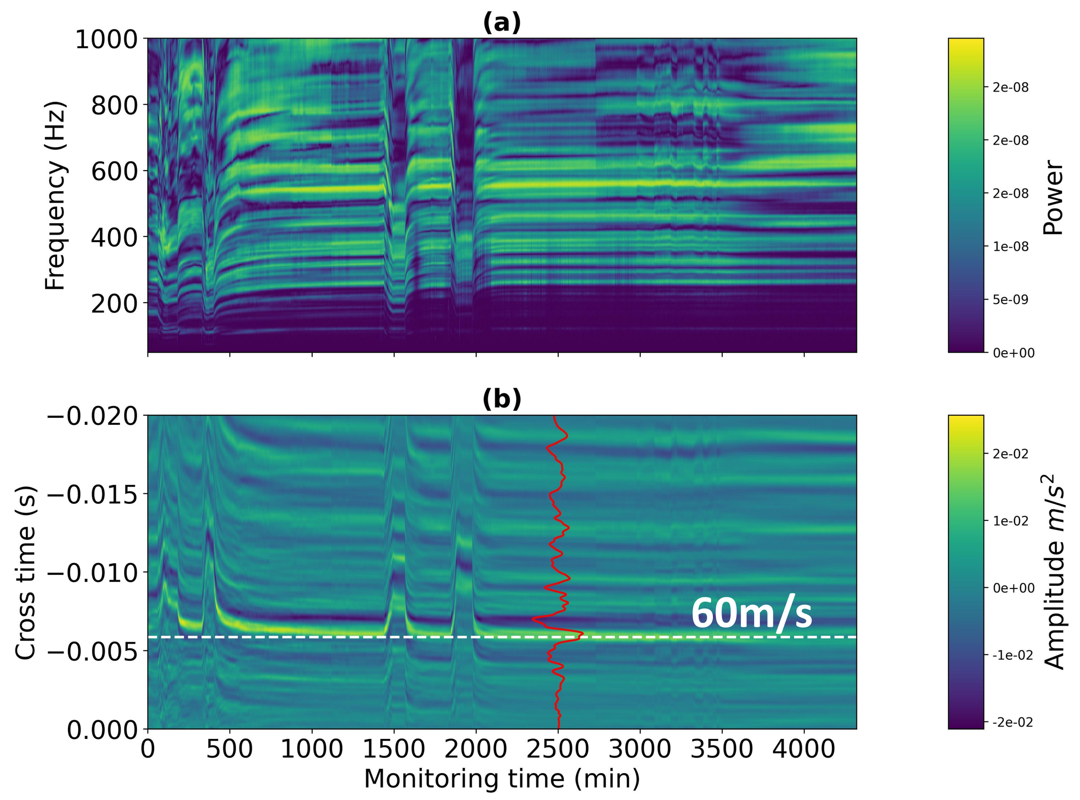
Disba library for Python

Velocity changes by the stretching method

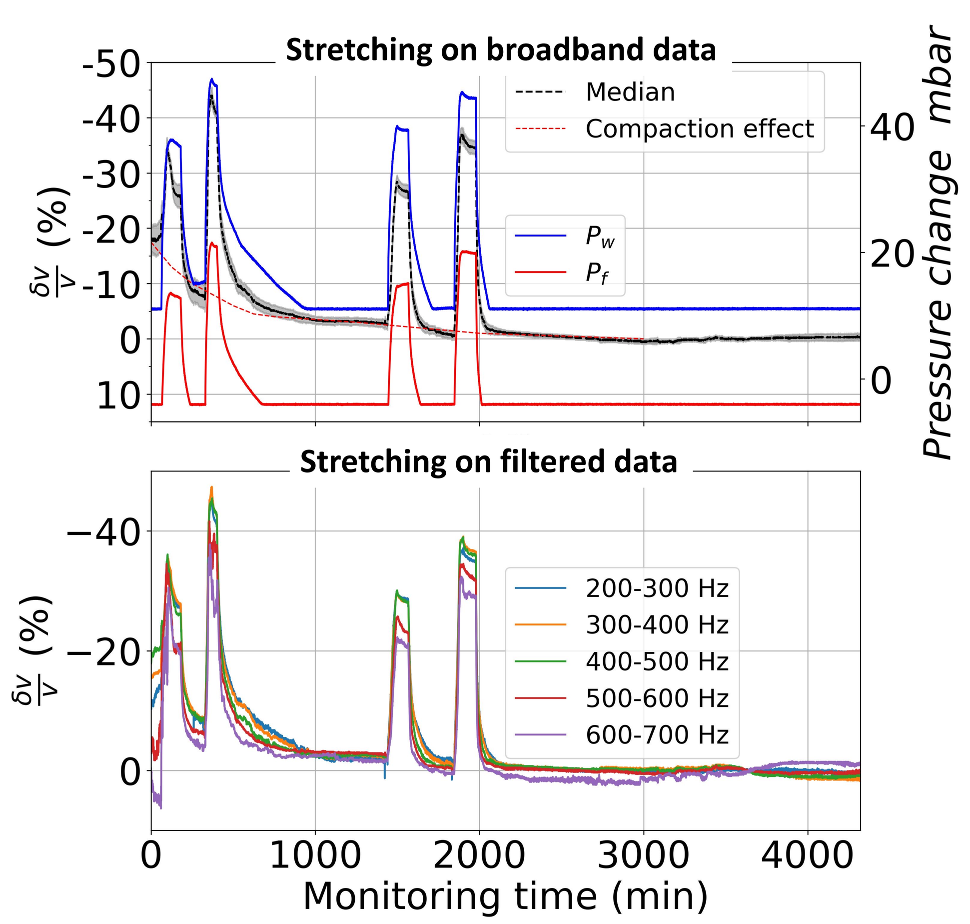
Correlograms are obtained by computing the crosscorrelation on 10s windows between two receivers (here d=0.4m)

During water filling times, we observe :

- ❑ a drop of the dominant frequency
- ❑ a drift in the time arrivals due to slower velocities



Crosscorrelation averaged in the [2300-3000]min time window (very stable period under low saturation) is used as the **reference for stretching**



Spectacular velocity variations are observed (>30%) which follow the pore pressure measurements

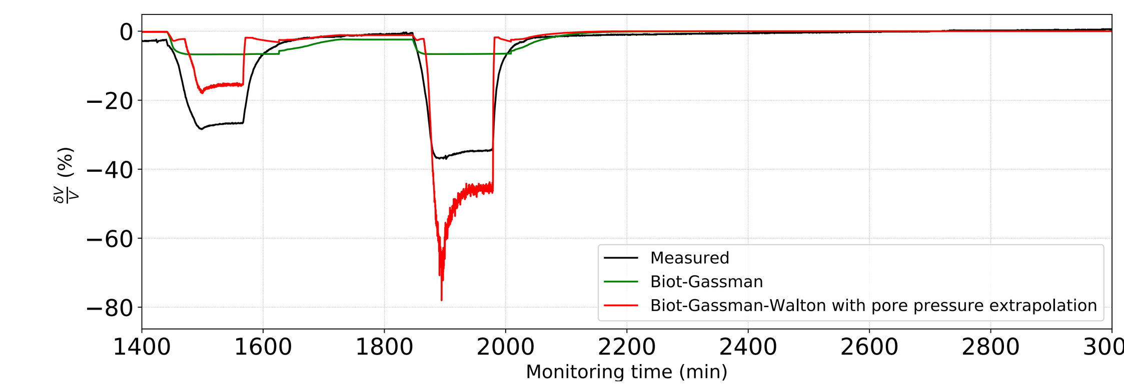
A drift is observed during the two first cycles due to a compaction effect

Discrepancies in velocity variations obtained for various bandwidths suggest **a possible effect of sensitivity kernels** that can be tested by using a complete Biot-Gassman approach that involves pore pressure effects

Predictions Vs Measurements

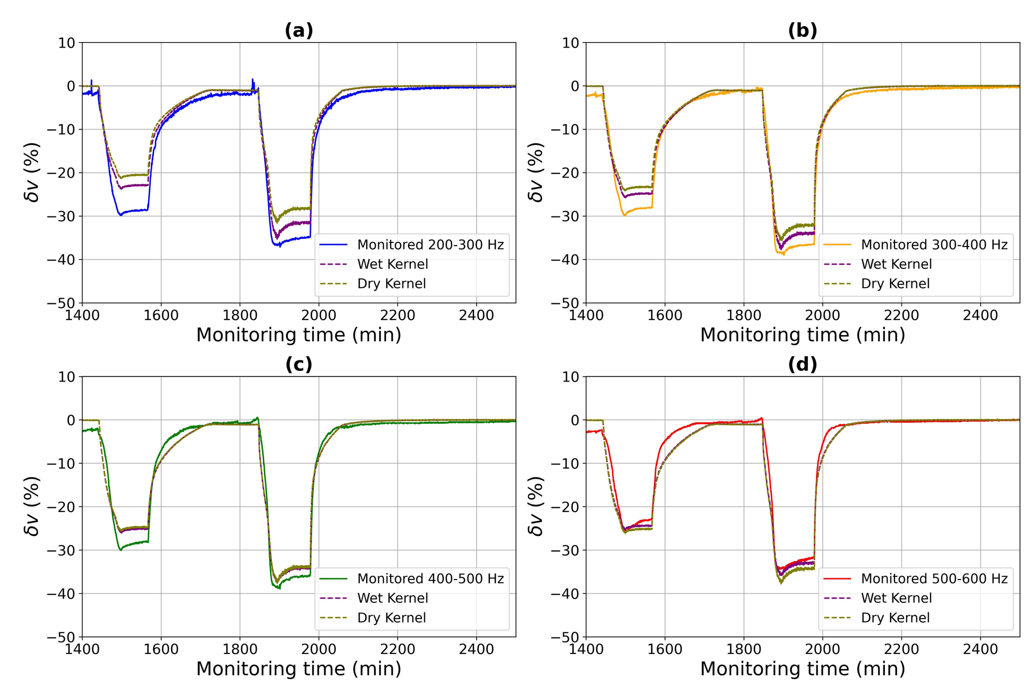
Saturation and pore pressure measurements allow us to predict velocity changes:

- ❑ **Within the Biot-Gassman fluid substitution assumption:** in this classical approach velocity changes are due to variations in bulk modulus and density. It clear fails in predicting huge velocity variations.
- ❑ **Within the Biot-Gassman-Walton approach:** that also accounts for the pore pressure changes extrapolated at every depth from. It predicts stronger variations but an unperfect match with observed velocity changes



Improving predictions needs to account for the sensitivity kernel!

- ❑ **Biot-Gassman-Walton model is weightened for every depth** using the sensitivity kernels of the Rayleigh wave
- ❑ It is performed in frequency ranges that involve various sensitivity kernels
- ❑ The match is remarkable and reproduces lower velocity changes for highest frequencies



Conclusion

- ❑ Seismic noise crosscorrelation has the ability **to monitor the vadose zone** when dealing with surface waves
- ❑ Due to strong saturation and pore pressure changes in the vadose zone, **velocity changes are spectacular (>30%)**
- ❑ The depth-intergation of Biot-Gassman-Walton models **weighten by sensitivity kernels** provide remarkable predictions

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