Time-lapse seismic experiments to constrain hydrodynamic parameters at the stream-aquifer interface

Keywords
Hydrogeophysics; seismic processing; time-lapse inversion; hydrodynamic modeling critical zone.

Scientific context of the internship

Porosity, permeability and saturation are properties of the Critical Zone (CZ) that naturally influence the seismic signal. Pressure (P-) and shear (S-) waves present, by definition, partially decoupled behaviors in the presence of fluids. The ratio of their propagation velocities (VP and VS respectively), or the Poisson's ratio therefore classically permit imaging the presence of fluids in rocks. This strategy however remains underused in near-surface applications, hence in hydrogeophysics. In the framework of the French program CRITEX, we showed how combined P-wave refraction tomography and surface-wave dispersion inversion can help describing both lithological heterogeneities of the CZ and spatial variations of its water content (Pasquet et Bodet, 2017). We then performed time-lapse applications of this approach on hydrosystems of distinct hydrogeological characteristics. Seismic signals where recorded at different spatial resolutions (using 20 to 500 m long profiles) and at different time scales (with hourly to yearly acquisition frequency). At each site, both spatial and temporal variations observed in P- and surface-wave data indicated marked changes of the mechanical properties in the CZ, helping to better describe not only the geometry, but also the dynamic of the hydrosystems (Dangeard et al., in press).

This approach has recently been experimented in the framework of the program PIREN-Seine to provide both spatial and temporal constraints on the hydrodynamic model of the Avenelles experimental basin (Seine et Marne, France). The preliminary studies of this hydrosystem relied on typical combined interpretation of sparse geological and hydrological data. Geophysical surveys, performed throughout the watershed, helped delineating the different compartments and identifying their connectivity with the stream network (Mouhri et al., 2013). Once a basin-scale global hydrogeological model established, hotspots were targeted with local high frequency monitoring stations to investigate its stream-aquifer exchanges. At these stations, recorded data (bank piezometers, stream water temperature and level, temperature profiles in the hyporheic zone) clearly showed contrasts in the dynamic of the hydrosystem along the stream network. However, the nature of the compartments and their associated properties, observed at the basin-scale, would not explain the data observed at the local scale. It highlighted the need for detailed description of the hydrosystem, at the stream-aquifer interface. One specific hotspot was thus selected to perform soundings and geophysical measurements of higher resolutions. Thanks to electrical resistivity tomography, P-wave refraction and surface-wave seismic imaging, we provided a description of the local heterogeneities both in terms of lithology and water content. The seismic experiments were then repeated with a two-month time step. At each time step, pseudo-2D sections of Poisson's ratio clearly showed strong spatial and temporal variations in saturation of the vadose zone. These results then helped providing updated constraints and boundary conditions to the hydrodynamic model (Dangeard et al., 2017).

Main aim of the internship

The preliminary results mentioned above involved: 1. a thorough estimation of the temporal variations of P-wave travel times and surface-wave dispersion; 2. a classic inversion of these data at each time step. During this internship, the master student will have to first explore existing time-lapse inversion methods for near-surface seismic data (e.g. Bergamo et al., 2016a,b) and then suggest their application to the 6 months data set provided by Dangeard et al., (2017). In the meantime, the hydrodynamic models will have to be updated with constrained inversions of the seismic data (by including other geophysical and geotechnical data). Additional high resolution geophysical surveys will be possibly performed to monitor the right bank of the site (see Dangeard et al., 2017 for more details). A last step of this internship will involve forward computations to develop alternative interpretations of the unsaturated zone in the vicinity of the stream-aquifer interface.

Required skills, qualification and training

We are opened to various education background/profile:

- qualifications or training in Earth sciences are not mandatory;
- knowledge in forward modeling techniques and inverse problems theory;
- knowledge in signal processing;
- basics in physics (mostly continuum and fluid mechanics);
- basics of rock physics/thermal properties of materials could help;
- interest (and motivation) in field experiment.

Location of the internship

The internship will mainly take place at UMR 7619 METIS a laboratory of Sorbonne Université, campus Pierre et Marie Curie in Paris.
The study will be supported by the PIREN-Seine and CRITEX research programs.

Duration and compensation

5 to 6 months compensated with the legal salary.

Supervisors

- Ludovic BODET (SU , UMR 7619 METIS);

- Marine DANGEARD (SU , UMR 7619 METIS);

- Agnès RIVIERE (MINES ParisTech).

For more information, please contact ludovic.bodet@upmc.fr

If you want to apply please send a CV, motivation letter --and recommendation(s)/referee(s) if possible-- to
ludovic.bodet@upmc.fr

References

Dangeard, M., Bodet, L., Pasquet, S., Thiesson, J., Guérin, R., Jougnot, D., and Longuevergne, L., in press, Estimating picking errors in near-surface seismic data to enable their time-lapse interpretation on hydrosystems, Near Surface Geophysics.

Dangeard, M., S. Schneider, L. Bodet, A. Rivière, R. Guérin, F. Réjiba, G. Hovhannissian, 2017. Vers une interpolation hydrogéophysique des propriétés hydrodynamiques de la subsurface : apports du « time-lapse » sismique. Rapport PIREN Seine 2017.

Mouhri, A., N. Flipo, F. Rejiba, C. De Fouquet, L. Bodet, B. Kurtulus, G. Tallec, V. Durand, A. Jost, P. Ansart and P. Goblet, 2013, Designing a multi-scale experimental sampling system of stream-aquifer interfaces in sedimentary basin, Journal of Hydrology, 504, 194–206.

Pasquet, S., Bodet, L. (2017). SWIP: An integrated workflow for surface-wave dispersion inversion and profiling. Geophysics, 82(6), WB47-WB61.