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Using passive seismic data at the CaMI Field Research Station, Newell County, Alberta Canada

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Summary

At the CaMI Field Research Station we recorded several weeks of continuous surface and borehole seismic data to study the feasibility of using ambient noise correlation (also called interferometry) to monitor CO_2 injection. We focus here on the October 2017 dataset (prior to injection), composed of 14 days of continuously recorded data at the 98 stations of a 3C-3D permanent array (receiver grid of 10 m x 10 m). We use a standard processing (mean and trend removal, 1bit, spectral whitening) and compute the 14 daily ZZ-correlations for the 4753 pairs of stations to reconstruct the Green's function between them. Daily correlations show stable waveform for the baseline dataset with a good correlation coefficient between the reference and the daily correlations. Variations in the elastic parameters of the subsurface due to CO_2 injection will directly affect the reconstructed Green's function, and passive recording should allow us to detect the induced change of the medium. Interferometry can also be used as a tomographic tool through the analysis of the dispersion curve of the reconstructed Green's functions. We compute the dispersion curves for few couples of stations. A detailed analysis will be undertaken to determine why some periods show outlier values, but the group velocities obtained are similar to those found in literature.

Theory

Ambient noise correlation studies are based on the principle that you can approximate the Green's function between two stations by correlating the continuous signal recorded at these two stations. Since the first application on real continuous noise data by Shapiro and Campillo (2004), ambient noise correlation is widely used for tomography purposes.

Since the result of the correlation depends of the properties of the medium between the two stations, if you change the elastic properties of the medium, the result of the correlation will also change. From this affirmation emerged the idea of using the ambient noise correlation (or interferometry) for monitoring purposes. For example, this method was applied on volcanoes (Duputel et al., 2009), on geothermal site (Obermann et al., 2015) and a feasibility studies were done at the Ketzin CO_2 storage field (Boullenger et al., 2015). The main challenge on that last application is the few changes of the medium due to gas injection, which make it difficult to detect by interferometry. This is particularly the case on the Field Research Station where the plan is to inject very small amount of CO_2 in the subsurface (<400 t/year, Macquet et al., 2018).

Application to the CaMI Field Research Station

The dataset used in the study was acquired from October 11th 2017 to October 25th 2017 (360 hours) on 98 instruments (3D array, 10x10 receivers, 10m receiver spacing) leading to 4753 possible correlations (and 98 autocorrelations). During this period, very small amount of gas was injected leading to small changes of pressure in the medium. The three last days of the continuous recording period were busy days on the field as active seismic survey was conducted.

a. *Green's function reconstruction*

We use the Python open source code developed by Lecocq et al. (2014) to process the continuous data (mean and trend removals, 1bit temporal normalization, [0.5 - 30] Hz spectral whitening) and compute the correlations.

Figure 1.a shows the ZZ correlations with a SNR > 14. We clearly see non-symmetry in the correlations which indicate a non-homogenous distribution of the sources of noise. However, Hadziioannou et al. (2009) show that the prefect reconstruction of the Green's function is not a necessary condition to use ambient noise correlation for monitoring purposes. Figure 1.b shows the stacked correlations having a SNR superior to 7 (causal and acausal parts are stacked). Red line corresponds to the velocity 240m.s^{-1}, which roughly corresponding the maximum energy in the correlation.

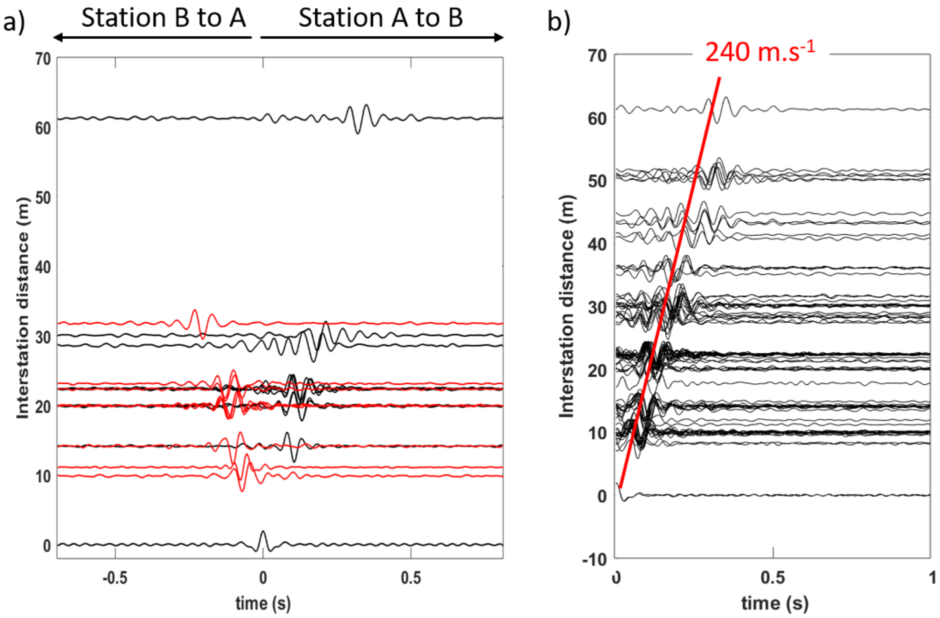

Figure 1: a) Empirical Green's function as function of interstation distance (for correlations with SNR>14). Red: Strong amplitude observed on acausal part of the correlation. Black: Strong amplitude observed on the causal part of the correlation. B) Empirical Green's function as function of interstation distance (for correlations with SNR >7). Causal and acausal parts are stacked.

b. Dispersion Curves

Surface waves are the dominant part of the reconstructed Green's function. They are dispersive waves and can be characterized by their group or phase velocities. We use frequency-time analysis (FTAN, Levshin et al. (1989)) to compute the group velocity dispersion curves of the stacked correlation for selected pairs of stations. Figure 2 shows the spectrogram and picked dispersion curves for 2 pairs of stations. The value for group velocities are coherent with the ones found in literature. Dispersion curves of surface waves are sensitive primary to the S-wave velocity of the subsurface, but also to the P-wave velocity and the density. Later on, these dispersion curves will be inverted to have elastic parameters models and will be compared with the ones obtained from other methods.

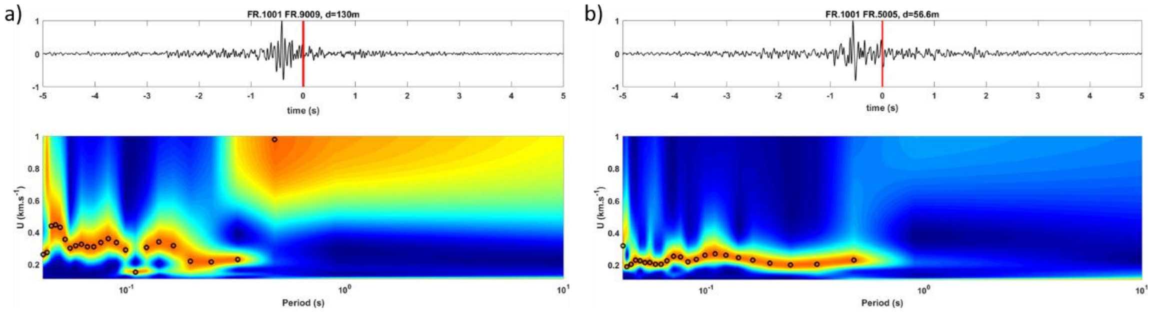

Figure 2: a) Results for a distance interstation of 130m (FR.1001-FR.9009). Top: correlation. Bottom: corresponding spectrogram. Maximum amplitudes picked are shown as black circles and correspond to the group velocity dispersion curve. b) Same for a distance interstation of 56.6m (FR.1001-FR.5005).

c. Toward monitoring

Application of using interferometry for monitoring purposes requires a good stability in the correlations. The October 2017 dataset can be considered as baseline as negligible amounts on CO_2 were injected during this period. In order to be able to detect small changes, we need to be sure that the baseline correlations remain similar with time. Figure 3 shows the reference correlation as the stack of the 14 days period on the top. Middle panel shows the 14 daily correlations. We can already see the stability in the daily correlations. Right panel shows the correlation coefficient between the reference correlation and the daily correlation (coefficient being 1 when signals are perfectly correlated).

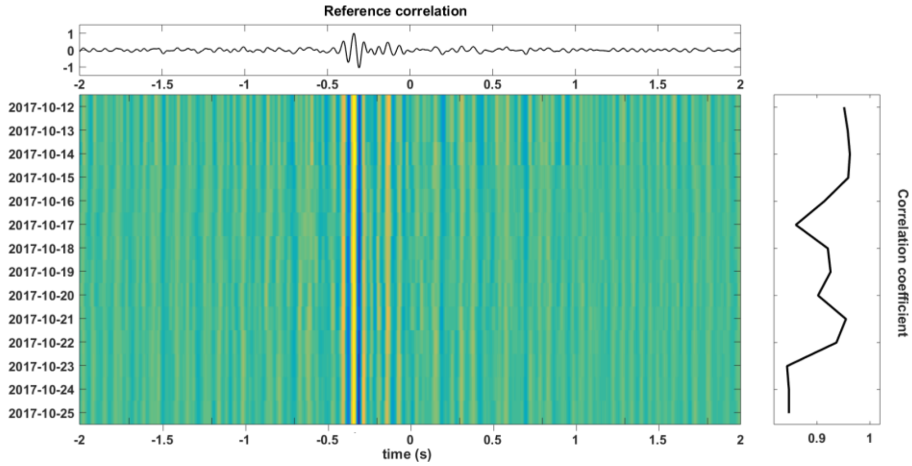

Figure 3: Stability of the correlation between the station 1009 and 9001 (80m apart). Top: Reference correlation (14 days stacked). Middle panel: Interferogram of the daily correlations. Right: Correlation coefficient between the reference correlation and the daily ones.

In the MSNoise package, Lecocq et al. (2014) implement the Moving-Window Cross Spectrum analysis (MWCS, Clarke et al. (2011)). We test the method on a subset of 5 stations (4 in the corners of an 80m size square, 1 in the center). Results are shown on Figure 4. Daily velocity variations show values of ± 0.02% (up to ± 0.05% for some specific pairs not shown here). We can also notice a general decrease in the velocity. Several authors (e.g. Mainsant et al. 2012), Gassenmeier et al. (2014), Hillers et al. (2015)) showed that natural phenomena such as wind, groundwater level, or temperature may have a strong influence on the results of interferometry. We expect such small on the elastic properties due to CO_2 injection at the Field Research Station that a careful study of the results needs to be done to proper understand the meaning of our results.

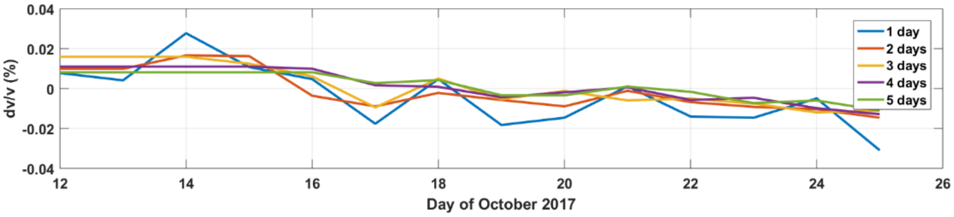

Figure 4: Mean velocity variations for different number of stacked days, for a subset of 5 stations.

Conclusions

The paper briefly described the methodology and shows the preliminary results of the processing that was performed on the passive seismic data collected during 14 days in October 2017. As very little injection tests were performed before and during this period, this dataset can be used as baseline reference for further studies.

Processing and correlation computation were done using the Python Code MSNoise (Lecocq et al., 2014). Resulting correlations shows asymmetric signal which will be further investigate to study noise directivity. However, correlation shows good emergence of the surface wave which allows the computation of group velocity dispersion curves showing values coherent with expectation.

Finally, we start to look at the stability in the correlations for this baseline dataset and the reconstructed Green's functions show good stability over time. We compute the velocity variation for a selection of station pairs. They show very low velocity variations (± 0.05% for specific pair of stations) with a general decreasing velocity. Further investigation needs to be done to analyze this result.

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