Ambient noise correlation study at the CaMI Field Research Station, Newell County, Alberta

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Summary

We recorded passive continuous seismic data at the CaMI Field Research Station to study the feasibility of using ambient noise correlation method as an additional tool to monitor and verify secure storage of the injected CO_2. We focus here on two aspects: (1) the near surface tomography, using 112 geophones along the 1.1 km trench and (2) the long-term monitoring of the velocity change using continuous seismic recording since October 2015 on 7 broadband stations. Due to the frequency range of the geophones used for the tomography part, the investigation depth remains shallow (up to 50 m depth). Nevertheless, a good near-surface velocity model remains important for active seismic processing. The V_S model obtained with ambient noise correlation method is similar to the one obtained from an active shear seismic source study. Concerning the monitoring using the ambient noise correlation method, the daily correlations between 2 broadband stations show good coherency. The velocity variation between the daily correlations and the reference are obtained using Moving Window Cross Spectrum analysis. The effect of the seasonal temperature change is clearly visible on the velocity variation curves. We also suspect an effect of the CO_2 injection on the velocity variation.

Ambient noise correlation method

The seismic ambient noise method (also called AN, or ANT for Ambient Noise Tomography) gives access to the approximation of the Green's function between two receivers by correlating the continuous signal recorded at these two stations. In other words, you can turn one receiver into a so-called virtual source by correlating the seismic ambient noise. The surface waves are dominant in the reconstructed Green's function, so the dispersion curves can be computed, group and/or phase velocity maps produced, then inverted to obtain V_S model. In addition to tomography studies, the use of ambient noise correlation technique starts to be used for monitoring purposes. As the Green's function is sampling the medium between 2 stations, if the medium changes (more or less scatters, change in velocities...), the correlations can be used to track these changes.

We use MSNoise Python package (Lecocq et al., 2014) to pre-process the continuous seismic signal (mean and trend removal, 1-bit temporal normalization, spectral whitening normalization) and compute the daily correlation between all the pairs of stations. A reconstructed virtual shot gather is shown on Figure 1. The yellow star shows the geophone turned into a virtual source. We can observe the surface wave (here Rayleigh wave as we use the vertical components) with a velocity of approximately 325 m.s^{-1}. We interpret the faster wave as a body wave. We compute the cross correlation between all the pairs of stations and obtain a starting dataset of 4098 interstation paths for the tomography application.
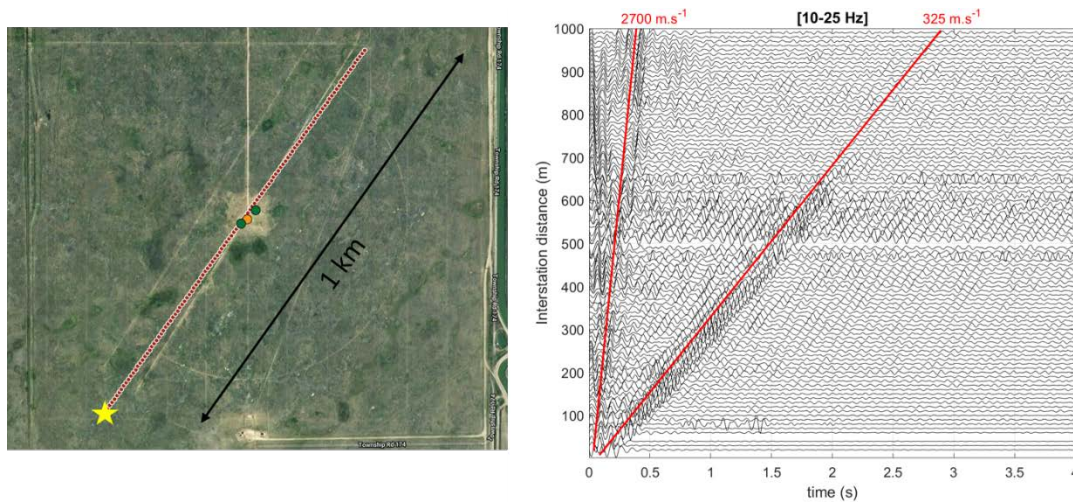
FIG. 1. Virtual shot gather reconstructed with the ambient noise correlation method. Left: experiment layout, yellow star is the geophone turned into a virtual shot. Orange dot is the CO_2 injection well, green dots are the observation wells. Right is the reconstructed shot gather.

Application to near surface tomography

We compute the group velocity dispersion curves of the reconstructed surface wave using Frequency-Time Analysis (FTAN, Levshin et al., 1989). We quality-controlled them based on the Signal to Noise Ratio of the correlation and the λ criteria (we only keep the path containing at least one wavelength). The interstation dispersion curves are regionalized (Barmin et al. 2001) to obtain a 2D section of the group velocity. Figure 2.b shows the 2D section relative to the averaged group velocity (Fig 2.a). It is difficult to directly compare group velocities (Vg) and S-wave velocities as their relation is not linear. Vg is mainly dependent of V_S but also depends the density, V_P, the attenuation... Nevertheless, the following considerations are true:

- Low group velocity can be related to low S-wave velocity;
- High frequencies are sensitive to shallow part when lower frequencies are sensitive to deeper part.

From these considerations, we can observe on Figure 2.b that:

- the velocities are increasing with depth;
- at shallow depth: velocity is lower on the SW part than on the NE part of the trench;
- at deeper depth: velocity is higher on the SW part than on the NE part on the trench.

These observations are coherent with the Vs model of Isaac and Lawton (2019) obtained using a shear source produced dataset. We use the SRFPython package (Lehujeur et al. 2018) to invert each local dispersion curve. It uses a Markov Chain Monte Carlo (MCMC) inversion to get the local Vs models. The 1D models are merged to get the 2D Vs section (Figure 2.c)
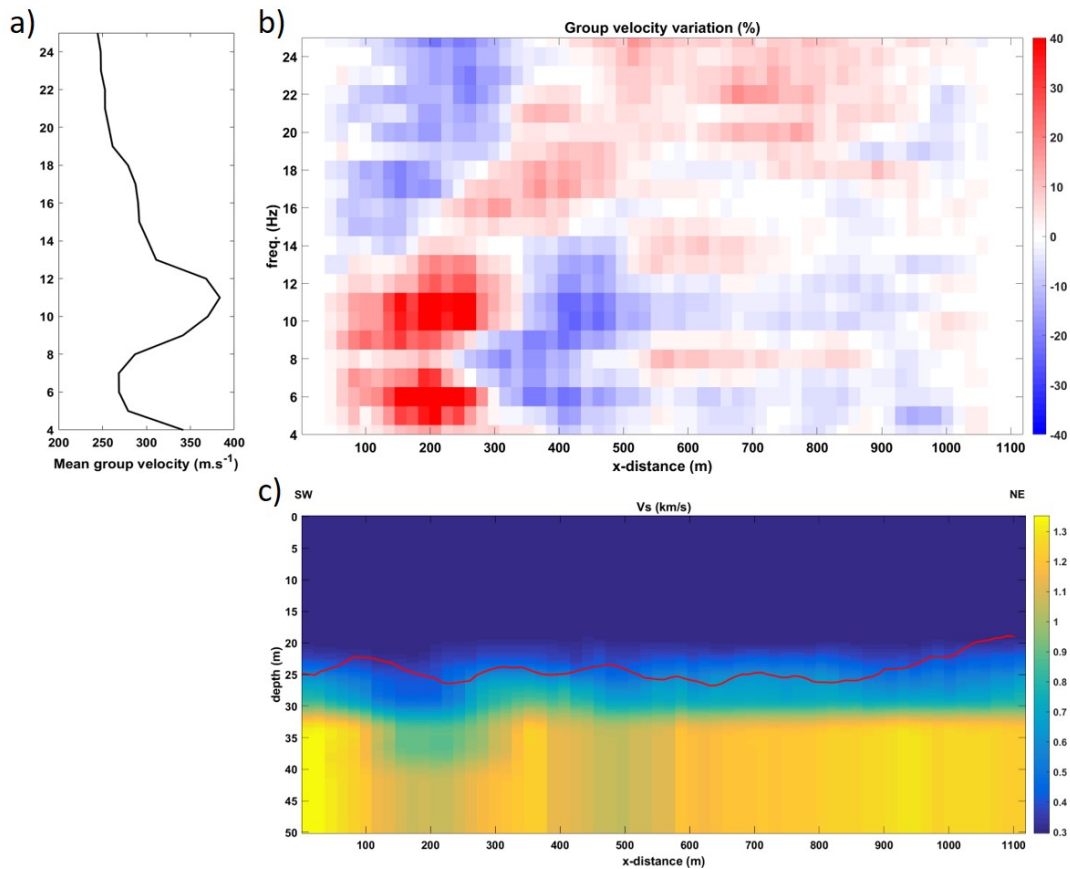
FIG. 2. a) Averaged group velocity curve. b) Group velocity variation compared to mean group velocity shown on a). c) Inverted V_S model along the trench. Red line is the bedrock depth obtained from shear wave source analyses (Isaac and Lawton, 2019).

Application to monitoring

In the MSNoise package, Lecocq et al. (2014) implement the Moving-Window Cross Spectrum analysis (MWCS, first introduced by Ratdomopurbo and Poupinet (1995), also called doublet method). For a detailed theory, lectors can refer to Clarke et al. (2011). Figure 3 shows the average velocity variation observed for all pairs of stations. The analysis is done in the [0.1-1]Hz frequency range, in the [0.5-5]s time window. Figure 3.a shoes the daily velocity variation as well as the smoothed curve (over 40 days). We can clearly see a good correlation between the smoothed curve and the average temperature (Figure 3.b). Figure 3.c shows the daily CO_2 injection, with the periods of injection highlighted in green. They seem to correspond to periods of velocity variation decreasing (Figure 3.a).
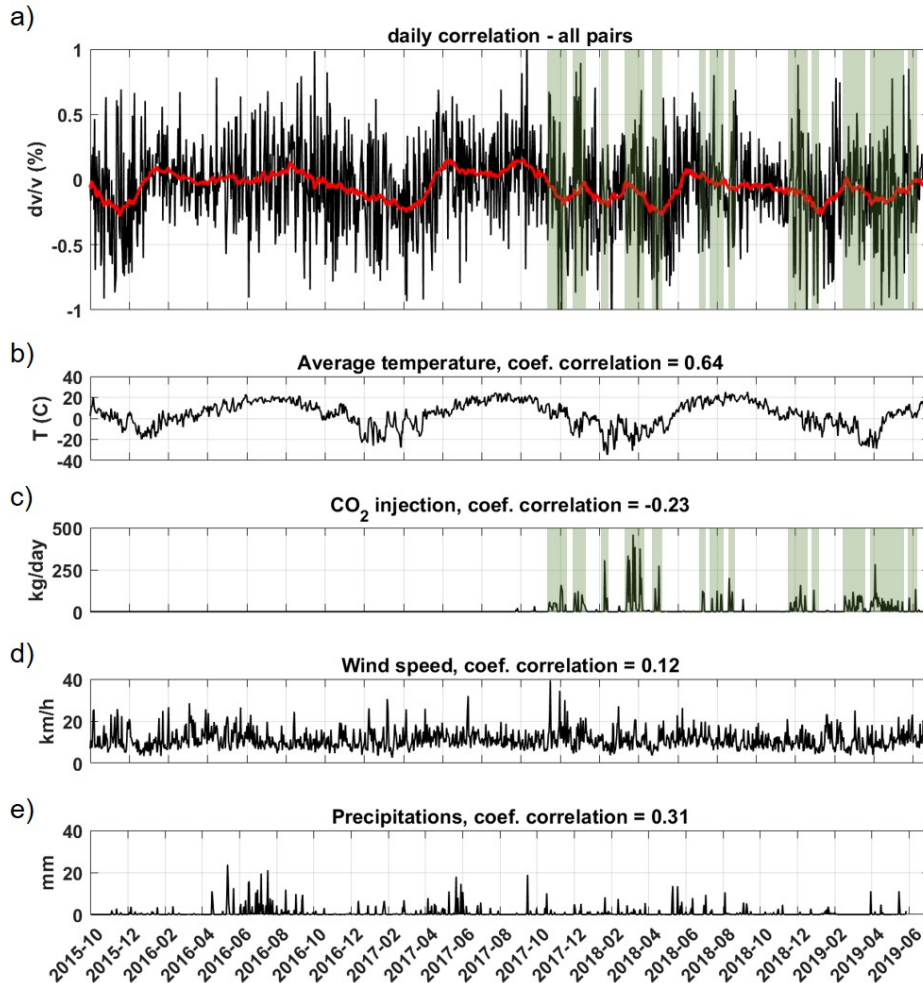
FIG. 3. a) Velocity variation from daily cross correlation. Red curve is the smoothed curve. b) Average daily temperature. c) Daily injection. d) Wind speed at 2m high. e) Rain precipitation.

Conclusions and Future Work

Concerning the imaging of subsurface with ambient noise; the method is already widely attested, especially among the crustal tomography field. The downside part in this study is the shallow depth of investigation due to the frequency range of the used geophones. The V_S model is coherent with other studies done at the Field Research Station. The near surface tomography work can be extended to the June 2019 survey. The 3D part of that experiment will be used to have a 3D Vs model of the subsurface. The trench part of the June 2019 experiment will be used to compare the velocity obtained during winter time (Feb. 2018, this study) and summer time (June 2019, future work) and determine the potential effect of the environmental changes on the near surface conditions.

Concerning the monitoring of CO_2 injection with the ambient noise correlation method, the main challenge at the Field Research Station is the weak amount of CO_2 that is planned to be

injected in order to simulate a leakage (Macquet et al. 2019). 500kg/day will induce relatively small plume size (compare to large-scale field) and small variation in elastic parameters. As the use of ambient noise can highly be affected by environmental changes, a very careful analysis of the system is required to fully understand which parameters influences the Green's function reconstruction and so which parameters can be the cause of the observed velocity variation. The 4 years of continuous recording on the broadband stations and several weeks on several denser surveys allow the study of the impact of the environmental changes on the ambient noise correlation method. The effect of the seasonal temperature is clearly visible on the velocity variation curves. We also suspect an effect of the CO_2 injection. Further analysis is required to confirm the first observations and be able to associate observed velocity variation to the correct parameters. Ultimate goal being to determine if whether or not the ambient noise correlation technique can be used to detect leakage of CO2. The monitoring work will be updated with the continuous acquisition on the broadband array. Since June 2019, seismic continuous acquisition was also done on 24 geophones. During that period, the CO_2 injection increases. Monitoring trough ambient noise correlation and trough events detection will be carrying on.

Acknowledgements

References

Barmin, M. P., Ritzwoller, M. H., and Levshin, A. L., 2001, A fast and reliable method for surface wave tomography: Pure App. Geophys., 1351–1375.

Clarke, D., Zaccarelli, L., Shapiro, N., and Brenguier, F., 2011, Assessment of resolution and accuracy of the moving window cross spectral technique for monitoring crustal temporal variations using ambient seismic noise: Geophysical Journal International, 186, No. 2, 867–882.

Isaac, J. H., and Lawton, D. C., 2019, Near-surface depth/velocity models at the CaMI Field Station: CREWES Research Report, 31.

Lecocq, T., Caudron, C., and Brenguier, F., 2014, MSNoise, a Python package for monitoring seismic velocity changes using ambient seismic noise: Seismological Research Letters, 85, No. 3, 715–726.

Lehujeur, T., Vergne, J., Schmittbuhl, J., Zigone, D., Le Chenadec, A., and EstOF Team, 2018, Reservoir imaging using ambient noise correlation from a dense seismic network: Journal of Geophysical Research- Solid Earth, 123, No. 8, 6671–6686.

Levshin, A., Yanocskaya, T. B., Lander, A. V., Bukchin, B. G., Barmin, M. P., Ratnikova, L. I., and Its, E. N., 1989, Seismic surface waves in a laterally inhomogeneous earth: edited by V. I. Keilis-Borok, Springer, New York.

Macquet, M., Lawton, D. C., Saeedfar, A., and Osadetz, K. G., 2019, A feasibility study for detection threshold of CO2 at shallow depths at the CaMI field research station, Newell county, Alberta, Canada: Petroleum Geoscience, petgeo2018–135.

Ratdomopurbo, A., and Poupinet, G., 1995, Monitoring a temporal change of seismic velocity in a volcano: Application to the 1992 eruption of Mt. Merapi (Indonesia): Geophysical research letters, 22, No. 7, 775–778.