Seasonal variation of dv/v at the Newell County Facility in Alberta, Canada

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Summary

The Newell County Facility is a pilot-scale CO2 storage site in southeastern Alberta, Canada, which was developed by the Containment and Monitoring Institute (CaMI) in collaboration with the University of Calgary. At this site, a small and controlled volume of CO2 is being injected at a depth of ~300 m to improve monitoring techniques. Ambient noise interferometry is one of the passive seismic methods that has been used for continuous monitoring. The ambient seismic noise cross correlations are closely related to Green's function of the medium. We observe a seasonal pattern in the noise cross correlations in the range of 0.1-1 Hz. The arrivals shift to earlier times during spring/summer and shift to later times during winter. These shifts in the arrivals exhibit ~1.25% variation in the relative seismic velocities (dv/v) during 2020. Variations in the dv/v follow the same pattern as changing temperature showing that these observations are sensitive to environmental conditions. We suggest that these variations are caused by the freeze-thaw cycle at the site.

Theory and workflow

The origins of seismic interferometry go back to a study by Claerbout (1968). Claerbout (1968) demonstrated that for a 1D medium bounded above by free-space and bounded below by a homogeneous half-space, the reflection response of a horizontally oriented medium for a source and receiver on the free surface could be obtained from the transmission response for a source located in the half-space.

The main steps consist of cross-correlating the acquired seismic recordings from a pair of receivers for each source and then summing up (stacking) the resulting cross-correlations. When correlating data from stations A and B – positive arrivals would correspond to signals traveling from B to A and negative arrivals would correspond to signals traveling from A to B. Surface waves are dominant in the reconstructed Green's function, so dispersion curves can be computed to measure group or phase velocities. These surface wave velocities can then be inverted to obtain a shear wave velocity model (e.g., Yanovskaya et al., 1989). Seismic interferometry applications can be categorized into two different classes: the first and the focus here, are techniques to obtain information about the medium that the waves propagate through, and the second, reconstruct information about the propagating waves themselves (Curtis et al., 2006).

We used 3 broadband stations during 2020, Figure 1 shows a map of the Newell County Facility, and the red squares show the location of broadband seismometers. We used data from stations FRS1, FRS4 and FRS5 as examples. We cross correlated the data between each station pair to obtain the associated Green's functions at the Newell County Facility. In order to remove unwanted signals, there are pre-processing steps that need to take place before cross-correlation. The employed data processing scheme is similar to the one described in detail by Bensen et al. (2007). The mean, trend, and instrument response were removed from the data, which will also be decimated to reduce the amount of storage space and computational time required. One-bit normalization was applied which consists of putting all the negative amplitudes to -1 and all the positive amplitudes to +1 (Campillo and Paul, 2003). Spectral whitening was used for frequency-domain normalization. Data corresponding to one day was cross correlated for each station pair. We used the MSNoise software which is a high-performance python package for ambient noise analysis (Lecocq, et al, 2014).

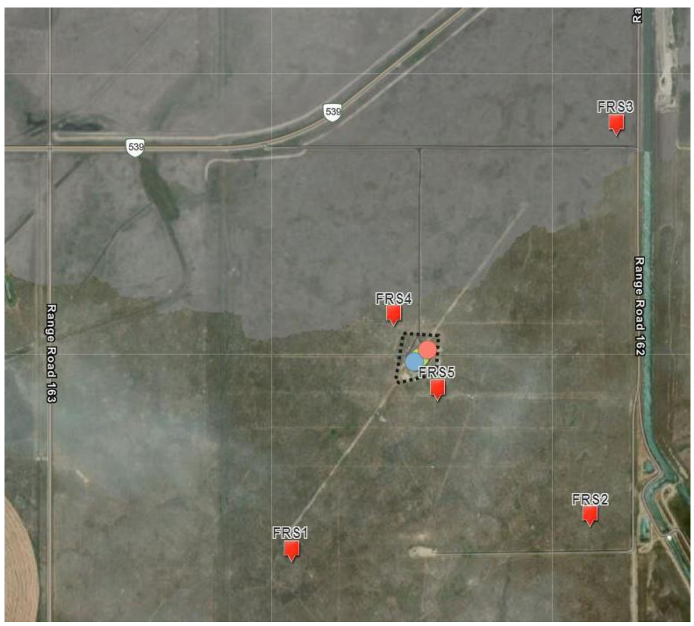

Fig. 1. Map of the Newell County Facility, the red squares are the broadband stations. The two circles in the middle (orange and blue) show the location of the observation well and the green one is the injection well.

Then we use the stretching method (Sens-Schönfelder & Wegler, 2006) to calculate the seismic velocity variations. This method compares a reference correlation (here we use the second two weeks of January) and a current correlation (here we use daily stacks throughout 2020). By comparing the shifts in the arrivals in the time domain between the reference and current stack, the velocity variation or dv/v can be evaluated.

Observations

Figure 2 shows stacked daily cross correlations between stations FRS4 and FRS5 near the injection well with the smallest interstation distance (250m) during 2020. For this plot, we used 0.1-1 Hz daily data. We observe stable arrivals in the correlated signals between stations FRS4 and FRS5. The arrival times are variable, and there is a clear pattern of them becoming narrower during spring/summer (mid-May till the end of August) and becoming broader during winter (beginning of October till the end of December). Considering the red arrival at ~5 s in the beginning of the year, it is visible that the arrival shifts to an earlier time at ~3 s in the middle of May and moves back to about 9 s in the beginning of October. The observed pattern suggests a seasonal change in the noise signature. The same pattern has been seen on the other cross correlations using other station pairs.

Figure 3 (a) shows the dv/v plot for three station pairs of FRS1-4, FRS1-5, and FRS4-5. FRS1 is located equally ~ 650 m apart from FRS4 and FRS5. For dv/v plots the lag time of 2-20s has been used to avoid direct arrival. Using three different station pairs the dv/v plots remain similar in each case and show a variation of a maximum of ~1.25%. Despite the similarities in the pattern of dv/v using different station pairs, it is observed that the closest two stations (FRS4-5) show the largest dv/v in 2020.

Figure 3 (b and c) plots display precipitation and ambient temperature data for 2020 at the Newell County Facility. Temperature rising to values above 0 degrees in mid-April and going back to below 0 degrees in mid-October is observed. This suggests that the ground would be frozen during this period at the Newell County Facility, and we observe a time-lagged correlation between the changes in the arrivals and the temperature signature. There is a big drop in the dv/v after July 1st, 2020, when there was a period of high precipitation (Fig. 3 (b)).

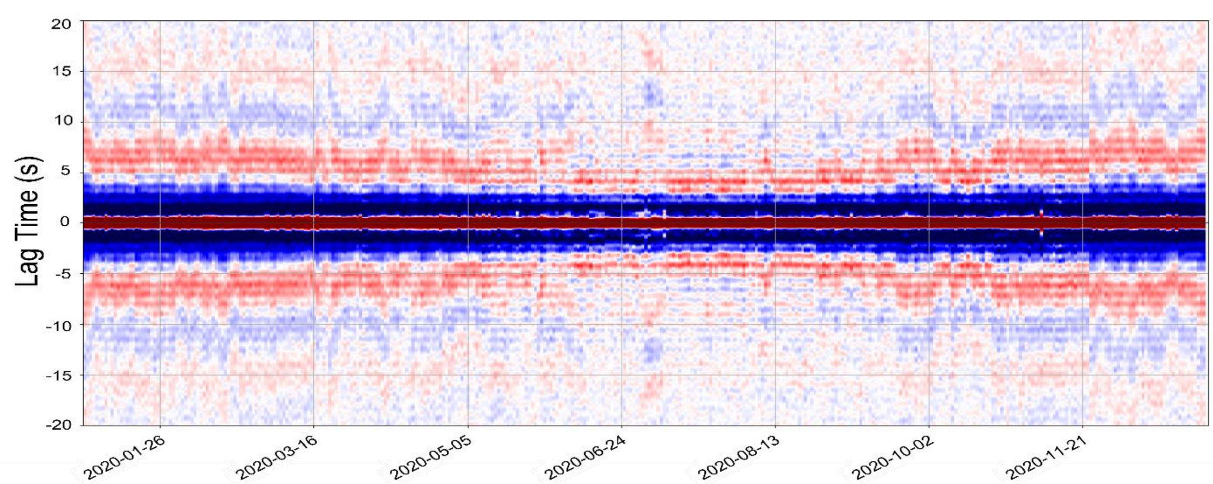

Fig. 2. Cross correlation of FRS 4 and FRS 5 throughout 2020. The red color shows positive arrivals and blue stands for negative arrivals.

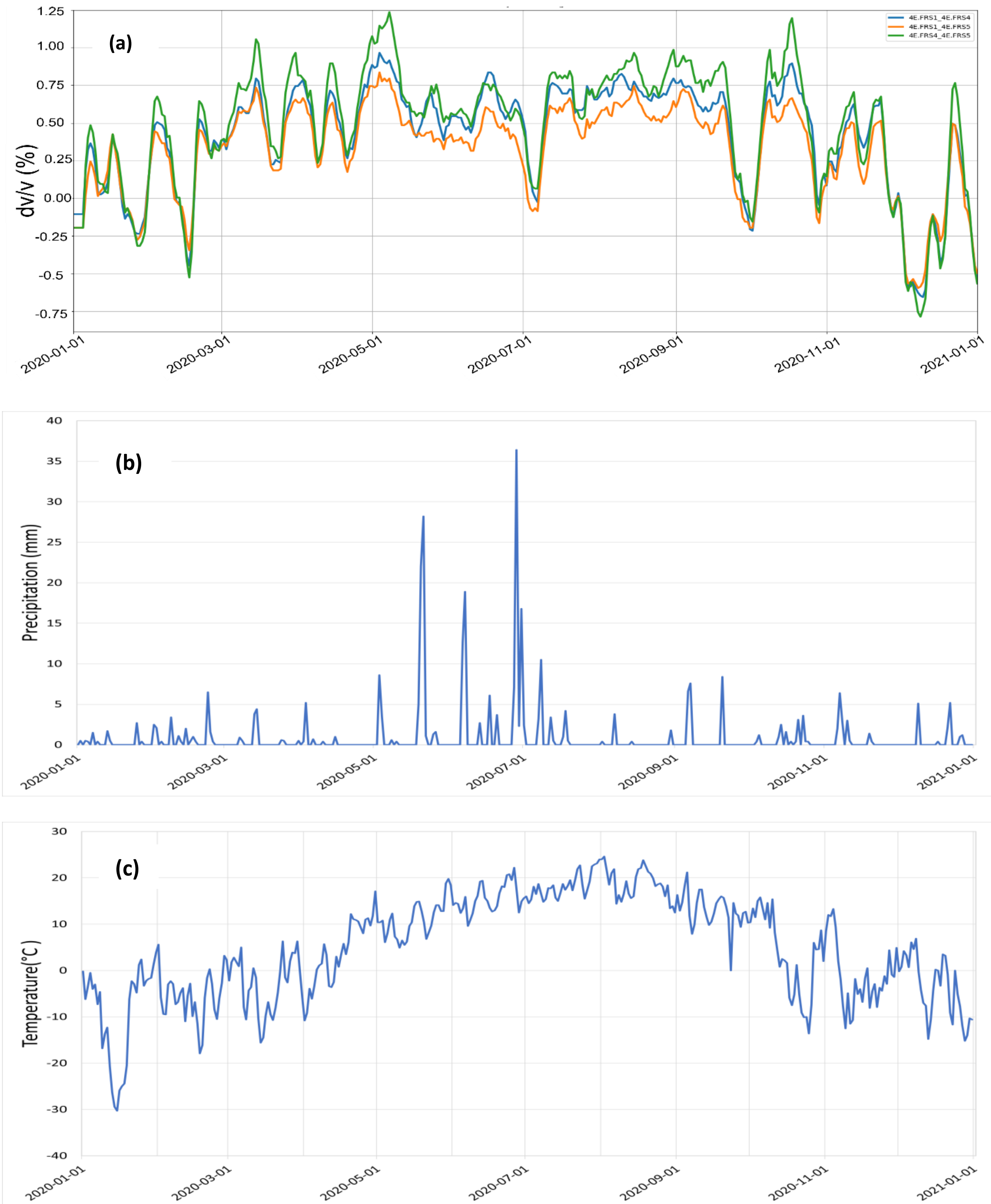

Fig. 3. (a) dv/v throughout 2020 using 2-20s of data for FRS1-4, FRS1-5 and FRS4-5. **(b)** Precipitation and **(c)** temperature plot for 2020.

Conclusions

We observe a seasonal pattern in the noise cross correlations in the range of 0.1-1 Hz. The arrivals shift to earlier times during spring/summer and shift to later times during winter, considering the arrival at ~5 s, this shift is about 4 s in 2020. This could be related to the freeze-thaw cycle at the site and/or changes in the groundwater level due to precipitation.

The dv/v at the site varies by ~1.25% throughout the year 2020. There is a correlation between temperature signature and dv/v shifts. This correlation shows that temperature influences changes in seismic velocities. We suggest that the variation in the signal is due to environmental conditions such as freeze-thaw cycles at the Newell County Facility. We also have looked at higher frequencies, in those frequencies' arrivals become asymmetric and there is not much coherency throughout 2020, it is more complex to measure dv/v in higher frequencies. For future work we will attempt to interpret dv/v using higher frequency bands and explore any correlation between dv/v variations and the CO_2 injection.

Acknowledgements

This research was undertaken thanks in part to funding from the Canada First Research Excellence Fund. The authors thank the University of Bristol for sharing the data presented in this work. We thank the CMC-CaMI Joint Industry Project members for their continuous support.

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