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RTM of a distributed acoustic sensing VSP at the CaMI Field Research Station, Newell County, Alberta, Canada

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Summary

We applied a reverse time migration (RTM) algorithm to distributed acoustic sensing (DAS) data from a walkaway vertical seismic profiling (VSP) acquisition at the CaMI Field Research Station at Newell County, Alberta, Canada. The RTM algorithm used a system of coupled first degree differential equations for pressure, vertical and horizontal particle velocities. As DAS data measurements are usually strain rate, we transformed them to vertical particle velocity before the RTM algorithm back propagated them. We tested the techniques of Daley et al. (2016) and Bóna et al. (2017) to do this transformation. We also tested the RTM with the original DAS data. Apart from a polarity reversal, there were no important differences between the different RTM tests. In addition, we migrated geophone data from the same VSP acquisition for comparison and found a similar imaging quality.

Introduction

The University of Calgary, in association with CMC Research institutes Inc., have a facility in Newell County, Alberta, called Containment and Monitoring Institute (CaMI) Field Research Station (FRS), where new technologies for carbon capture and storage (CCS) monitoring are being developed (Lawton et al., 2015). The plan is to inject up to 400 tonnes of CO_2 per year over 5 years inside water-saturated sandstones within the Upper Cretaceous formations, with overlying shales and mixed sand/shale sequences forming the cap rocks (Macquet et al., 2019).

To monitor the CO_2 injection, multicomponent geophones and state-of-the-art distributed acoustic sensing (DAS), that uses fibre optic cables (Daley et al., 2013), are permanently installed in two wells, a trench and an area around the injection facilities (Lawton et al., 2017).

In this abstract we perform an acoustic RTM of the walkaway VSP DAS data from the CaMI site. The plan is the following. We first explain the finite difference scheme we used for modelling and migration, then we mention the imaging condition we used. Following that, we explain how we transformed strain rate, what DAS measures, to particle velocity, that is what our RTM migrates. Finally, we apply the RTM algorithm to the real data and show the migration results.

Theory

We use the finite difference system defined in Liang et al. (2018). This is a staggered system in pressure P, vertical v_z and horizontal particle velocity v_x with density ρ and first Lamé parameter λ:

$$\begin{aligned}
\frac{\partial P}{\partial t} &= \lambda\left(\frac{\partial v_x}{\partial x} + \frac{\partial v_z}{\partial z}\right) + s \\
\frac{\partial v_x}{\partial t} &= \frac{1}{\rho}\frac{\partial P}{\partial x} \\
\frac{\partial v_z}{\partial t} &= \frac{1}{\rho}\frac{\partial P}{\partial z}
\end{aligned}$$

where the source s is injected in the pressure equation.

We implement the standard RTM algorithm (Baysal et al., 1983) for walkaway VSP DAS data using the imaging condition for vertical particle velocity v_z as the straight DAS fibre is mainly sensitive in the axial direction (Hartog, 2018), and in vertical VSP this direction coincides with the z axis. The normalized imaging condition is the following:

$$I(x,z) = \frac{\int_0^T v_z(x,z)\hat{v}_z(x,z)dt}{\int_0^T v_z(x,z)^2 dt},$$

where the hat symbol "ˆ" indicates back propagation, the denominator term is used to correct the source illumination and T is the maximum time recorded.

A vertical DAS measures vertical strain rate $f=\partial\epsilon_z/\partial t$ where ϵ_z is the strain along the z axis. In order to apply the imaging condition, we must transform this strain rate to vertical particle velocity. We test two approaches. The first one is from Daley et al. (2016):

$$v_z(z) \;=\; -c(z)\int f(z)dt, \qquad (1)$$

where f(z) is the fibre response and c(z) is the apparent particle velocity along the well measured from the first arrivals moveout. The second approach is from Bóna et al. (2017):

$$v_z(k_z) \;=\; f(k_z)\frac{-ik_z}{(1-e^{ik_zL})\,(1-e^{ik_zG})+\gamma}, \qquad (2)$$

where L is the pulse length, G is the gauge length and γ is a small constant used to avoid division by zero. This filtering operation is performed in the wavenumber domain k_z.

Figure 1 shows the imaging flow that we follow. First the DAS data is transformed to vertical particle velocity data. Then the source wavelet, P-wave velocity and density models are used to migrate these transformed vertical particle seismograms.

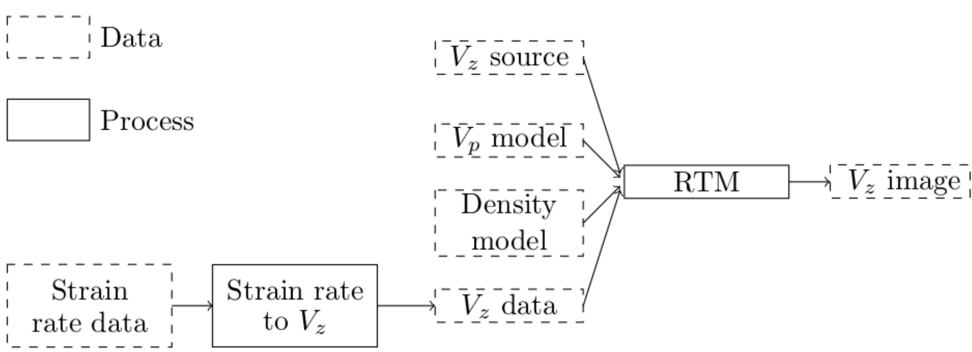

Figure 1. Imaging Flow. The DAS seismograms (strain rate) are transformed to vertical particle seismograms. Then they are migrated using a source wavelet, P-wave velocity and density models.

Results

The real data set is a walkaway VSP DAS composed of 17 shot gathers with spacing between 10m and 30m. The source was an IVI EnviroVibe with a linear sweep from 10Hz to 150Hz. There was a vertical DAS fibre with gauge length equal to 10m and traces from the surface to

320.25m deep every 0.25m (Gordon, 2019). There were also 24 multicomponent geophones from 191.25m to 306.25m every 5m inside the well. Figure 2 shows plan and profile descriptions of this acquisition.

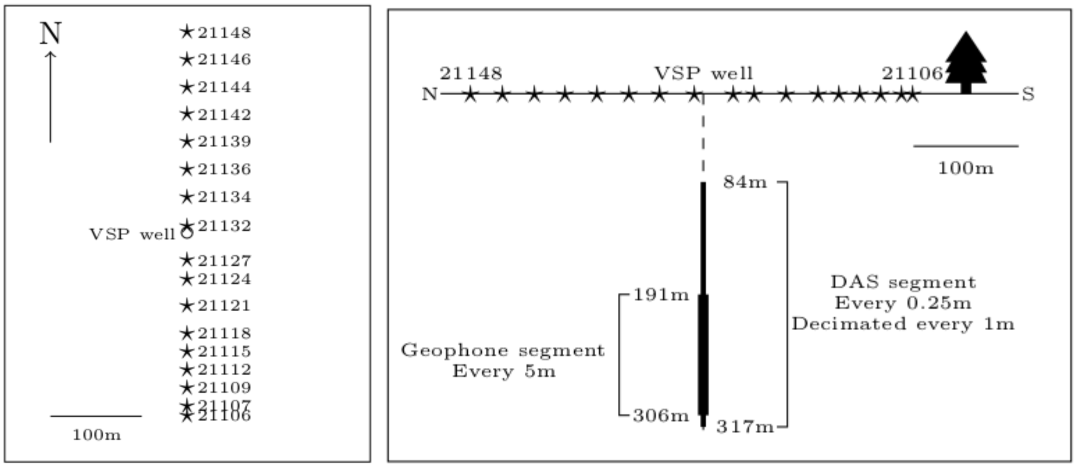

Figure 2. Plan (left) and profile (right) descriptions of the VSP acquisition at CaMI FRS. The star symbols are the shot positions while the circle is the well location.

Processing for both DAS and geophone data sets included geometry and first break picking, wavefield separation through median filtering and F-K filtering, gain for spherical spreading and transmission loss, and deconvolution of upgoing wavefield (Gordon, 2019). We select the DAS data from 84m to 317m every 1m because this interval is less noisy, and its size is adequate. Figure 3 shows the processed DAS VSP upgoing data set.

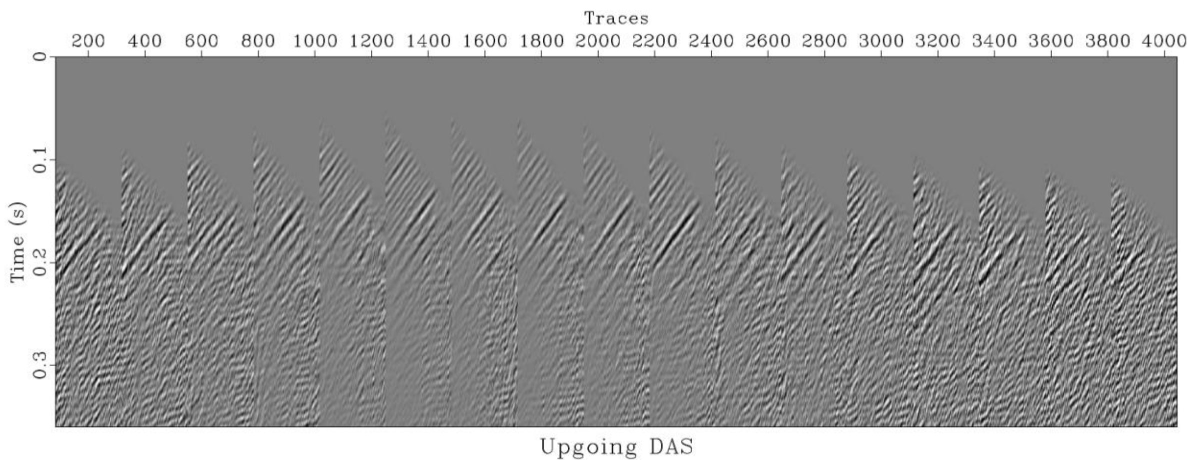

Figure 3. The 17 VSP DAS upgoing shots from 84m to 317m every 1m (Gordon, 2019).

Before feeding the RTM algorithm with the DAS data we transform it to vertical particle velocity using equations 1 and 2. For equation 1 we measured the direct wave velocity at the shot gather with the closest source to the well and found a constant apparent velocity of c=3500m/s. For equation 2 we use a gauge length G=10m and ignore the pulse length term. We also perform the RTM without transforming the DAS data and with the geophone data. Figure 4 shows the migration results.

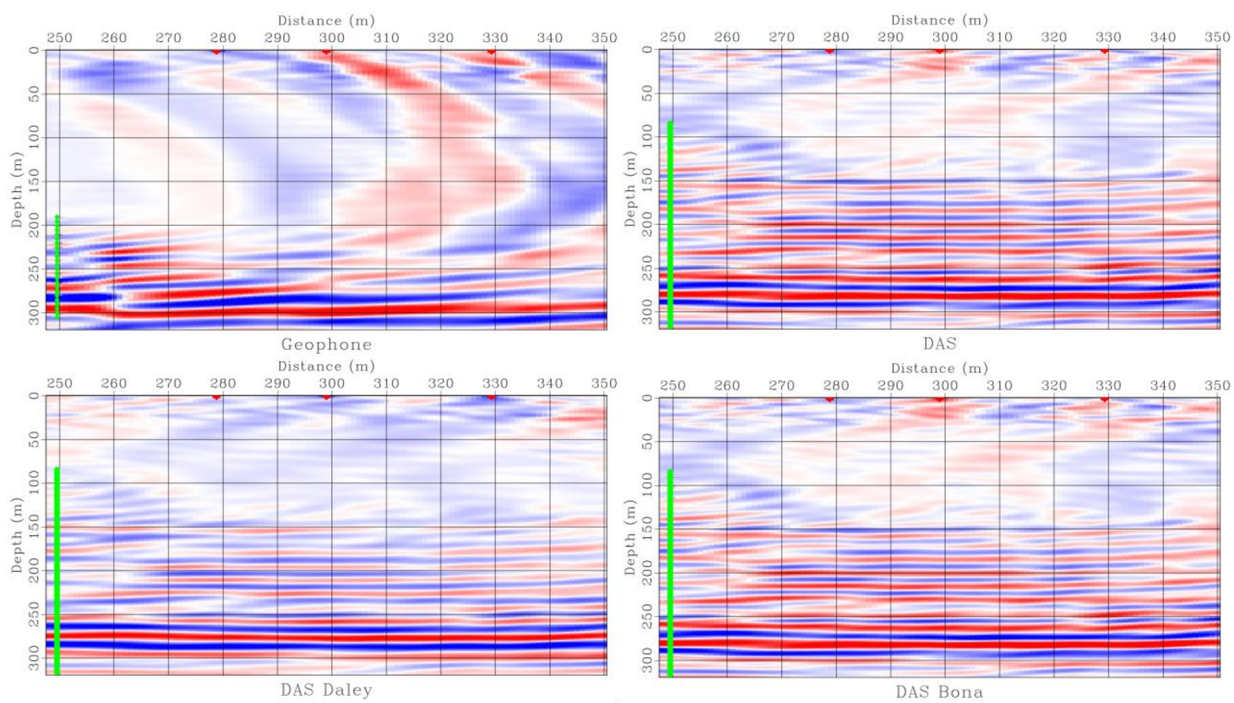

Figure 4. Top row left is the RTM from 24 vertical geophones located inside the well (green dots) between 191m and 306m deep every 5m and 17 source positions placed at the surface (red crosses). Top row right is the RTM from a DAS fibre located in the well (green line) between 85m and 317m deep. It uses the same sources of the previous figure. The DAS data was not transformed before being used in the RTM, i.e. strain rate was back propagated by the migration algorithm. Bottom left uses the same DAS and sources configuration but transforms the strain rate measurements into particle velocity using the technique of Daley et al. (2016). Bottom right also transforms DAS measurements to particle-velocity, but it uses the technique of Bóna et al. (2017).

Conclusions

RTM of the walkaway VSP DAS data from the CaMI Field Research Station is possible with the current data quality. This RTM have similar quality than the RTM from geophone data so we believe it could be used to perform monitoring at this facility. There were no apparent differences between the three RTM approaches we tested but we think a more detailed analysis is still needed.

Acknowledgements

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