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Using Surface Waves Instead of Abusing Them for seismic data processing – a Canadian oil sands case history

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Summary

Instead of treating surface waves as a nuisance to only be removed in signal processing, recent efforts have shown that we can extract valuable information from them. In a production environment, we can now model and robustly subtract ground roll from the reflected signal and also gain a greater understanding of the near-surface velocities. To this, we present an recent example displaying the benefits of this technology.

Introduction

The basis of this case history is on a high-resolution/high-density 3D3C seismic dataset which was acquired for a commercial Steam Assisted Gravity Drainage (SAGD) project in the Athabasca oil sands in Alberta. The reservoir is at a depth of about 300m. For such a shallow target, the ground roll and the reflection data interfere with each other in a more detrimental way than with a conventional survey with a much deeper target. For converted-waves, the problem is exacerbated since typically the frequency range of the reflections and ground roll is very similar, making it harder to separate with confidence. Suppressing the ground roll that dominates the shot records is therefore critical for seismic imaging and subsurface characterization.

For years, land acquisition efforts have focused on methods to suppress ground roll through array filtering built from various source and receiver configurations. The downside to this type of filtering is that intra-array statics cannot be corrected for, this unfortunately alters the resolution of the seismic images by potentially irreparably smearing the high frequencies. Point receiver single sensor surveys are thus better suited for preserving high frequencies and ground roll filtering efforts can no longer be partially handled in the field. Conventional seismic data processing methods to remove the ground roll from the shot records typically try to isolate the coherent energy via frequency and velocity discrimination. These procedures are often imperfect because the ground roll is broadband, very slow and very often spatially aliased. The presence of near surface heterogeneities and rough topography complicate this matter further. If surface waves have been inverted in geotechnical engineering applications for characterizing the very near surface for quite some time, their application to land seismic data is more recent (Roy and Stewart, 2011). In the following, we describe a method derived from a model-based approach referred to as Surface Wave Analysis, Modelling and Inversion (SWAMI).

Method

SWAMI is an integrated workflow for the near surface characterization and for the coherent noise attenuation. In conjunction with up-holes it can provide a near surface model even in complex areas. The workflow consists of three stages:

1. *Analysis:* takes raw data as input, defines the offset range which best represent the frequency content of the groundroll, and extracts the propagation properties of the surface waves; in particular their dispersion.

2. *Modeling and subtraction:* uses extracted dispersion volume, along with the seismic data, and generates a model of the ground roll which is then adaptively subtracted from the input data. The benefit of this is that at no time are the gathers transformed, thus making the process robust and fast to perform. Note also that no mute was used to isolate the noise model.
3. *Inversion:* takes the dispersion volume and creates a near surface velocity model by solving an inverse problem. This velocity model can be used to derive static corrections for converted wave processing. It can also be integrated as a near surface velocity model for depth imaging.

In this case history, the aforementioned 3 steps were performed. The first two were used to noise attenuate the surface waves whereas step 3 is used to improve the converted wave data processing. Using this method has been very effective in isolating and subtracting the surface waves from the seismic records on all components as we'll detail below.

Field application – PP data

First we perfomed the surface wave analysis and created the dispersion volume which was used to generate a noise model which was then adaptively subtracted from the input data figure 1 (a) and (b). As shown in these figures, SWAMI's ability to handle multiples modes of ground roll, scattered energy and aliased energy has given it the ability to attenuate nearly all of the low frequency ground roll energy present in the gathers. With this result, it is then much easier to use a mild application of the more conventional linear noise attenuation techniques while lowering the risk of harming the primary signal.

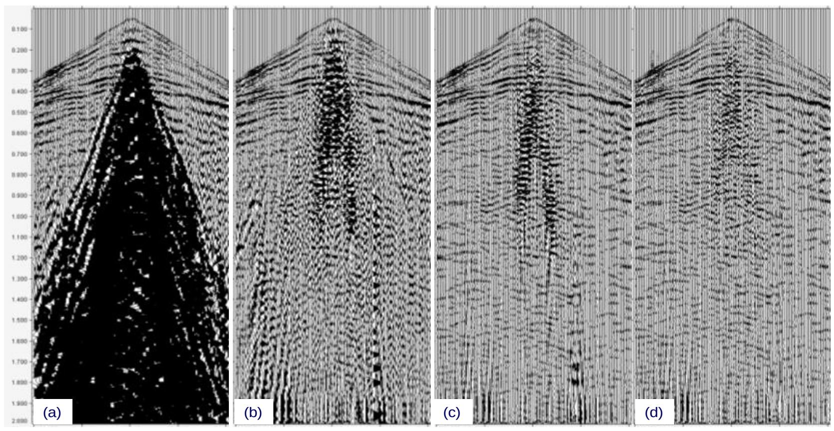

Figure 1: Oil sands shot gathers. (a) raw data; (b) after SWAMI noise attenuation; (c) cascaded with non-uniform coherent noise attenuation; (d) after additional noise attenuation.

Following SWAMI, a Non-Uniform Coherent Noise Suppression method which honours true coordinates and handles the irregularity of the acquisition geometry was applied to remove the remaining coherent noise, followed by the Anomalous Amplitude Attenuation that attenuated the residual noise, as seen in Figures 1(c) and (d) respectively.

Field application – PS data

A similar workflow was independently applied to the horizontal components. Initial processing of the converted wave data involved the usual orientation analysis to allow a proper rotation of the horizontal components to radial and transverse. To this data, a surface-consistent amplitude correction was calculated, and the source statics derived from the P-wave processing were also applied.

A benefit realized with this method is that it provides continuity between the radial and transverse signal processing. Testing concluded that surface-waves modelled from the radial component but applied to the transverse component performed equally as well in noise attenuation as those derived and applied to the transverse component independently. Thus using a common input to the modelling phase was deemed an acceptable and preferable method (Figure 3).

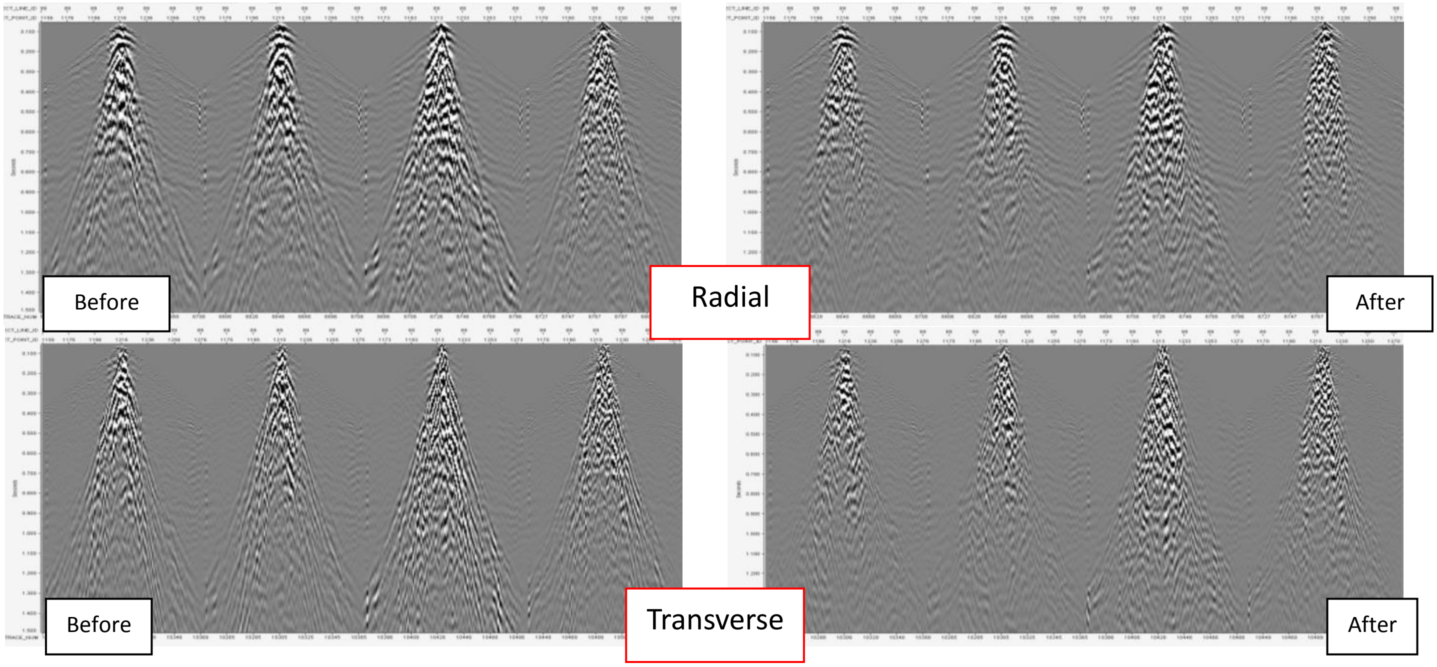

Figure 2 *The radial and transverse components before and after surface wave attenuation and the noise removed*

The next question that must be answered is the amount of surface-wave energy still present on the transverse component. In theory, this should be minimized after rotation but with the confidence that this was performed correctly, this may be an indicator of near-surface horizontal transverse isotropy (HTI) or an effect of a tilted layered system. In either case, it is an observation that does warrant additional investigation.

Near-Surface Shear Velocity Model

The additional benefit now realized is the ability to derive a near-surface Vs model from which can be derived a shear wave statics solution that is directly applicable to converted-wave processing. The depth of this model is directly linked to the amount of low frequency that can be accurately tracked on the dispersion curve. Once an initial model is derived (Figure 3), smoothing and editing are performed to produce a stable model from which statics can be calculated (Figure 4).

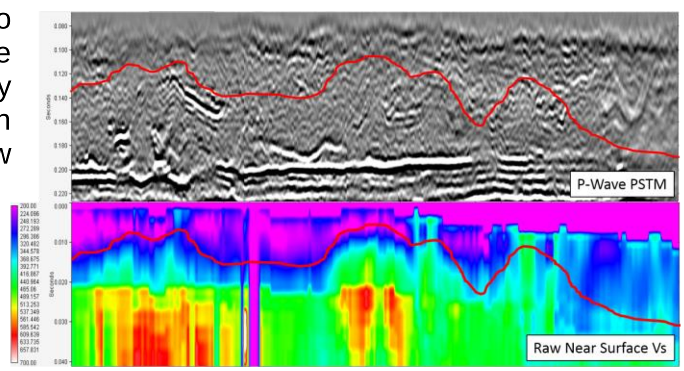

Figure 3 *Comparing the raw Vs velocity field to the shallow P-wave PSTM section. Similarities at this early state can be noted.*

The near surface model statics were applied to the PS-gathers. These gathers were then stacked into a common receiver stack along with the source statics derived from the P-wave time processing (Figure 5). A positive uplift was observed moving the reflected horizons closer to their expected position. While this survey did not contain the large receiver static variations observed on other surveys, the verification of this method provides an alternate approach to determining statics (particulalrly the long-wave component) which is more geophysically driven and independent of current horizon based methods. Verification of the near surface velocities via statics derivation also quantifies that this model should be a viable method for converted-wave pre-stack depth migration model building.

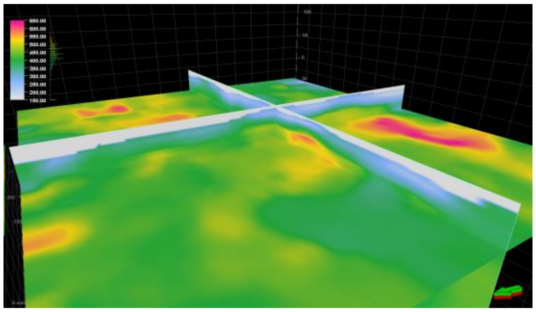

Figure 4 *The near surface Vs velocity model after smoothing*

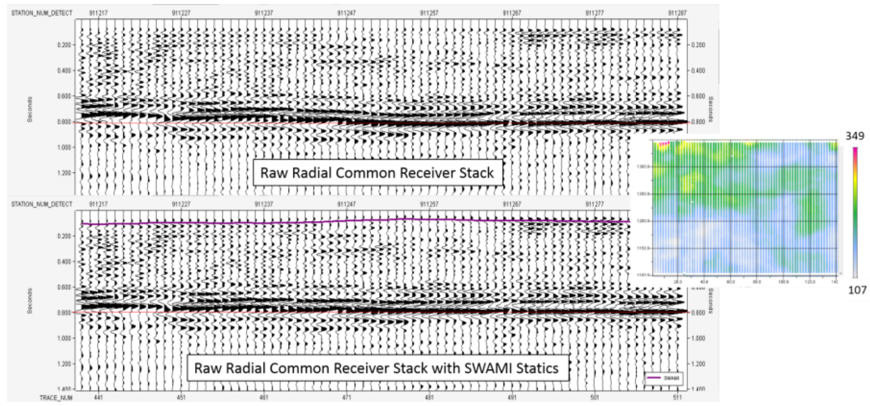

Figure 5 *Application of receiver shear statics derived from the near surface model and map of calculated values*

Conclusions

Like many struggles we face, the better we understand the underlying fundamentals the better we can find a solution. Being able to isolate surface waves has now allowed us to model and adaptively remove without harming primary energy. With the robustness this offers, future acquisition efforts may wish to attempt to enhance, rather than suppress, these waves. Processing technology has proven effective in suppressing them and, beyond that, surface-waves may provide the opportunity to glean new information to help build a better Earth model. Further to converted-waves in particular, the ability to derive a geophysically based receiver statics solution has long been a goal. As the popularity of C-wave PreSDM imaging grows, having an accurate near-surface shear velocity model will prove to be equally invaluable.

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