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Reduction of Noise Effects on Low Frequency Passive Seismic Data

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SUMMARY

Anthropogenic noise effects have always been a great concern for passive seismic because they are usually strong and difficult to remove. The problem is addressed by analysis of 2D (time-space) attribute sections derived from the recorded data. On the attribute sections transient noise appears as isolated points or distinctive linear trends and therefore can be suppressed by common filtering techniques. We applied the approach on a passive seismic data set from a survey line at an oil and gas field in Voitsdorf, Austria. The data set is noisy and the presence of hydrocarbon reservoirs could not be convincingly indicated by conventional analysis techniques. Attribute sections, after being filtered to reduce noise effects show a good agreement between reservoir locations and high amplitude trends on the sections. A modelling study reveals that the anomalies observed on the attribute sections match well with attribute values computed from synthetic data.

Introduction

Studies at various oil and gas fields worldwide have shown low-frequency spectral anomalies in the passive surface particle velocity signals that have a good correlation with the location of hydrocarbon (HC) reservoirs (e.g. Dangel et al., 2003; Mastrigt and Al-Dulaijan, 2008). The main observation is an increase of spectral amplitudes in the low frequency band of the vertical component of the data approximately between 1 and 6 Hz above HC reservoirs. The phenomenon has drawn a lot of interest recently because of its potential of being a new hydrocarbon reservoir indicator. However, as a passive measurement, the low frequency energy of the natural wave field is influenced by several undesirable factors such as transient anthropogenic noise (Hanssen and Bussat, 2008) and various kinds of surface waves (Berteussen et al., 2008). Therefore, careful processing steps are required before interpretation to avoid misleading results.
Unfortunately, due to high cost of delicate instruments passive seismic surveys are usually performed by only a couple of dozen seismometers deployed at a spacing of few hundreds meters instead of the dense arrays with thousands of geophones in active seismic surveys. Because of the small number of synchronized data points and the extremely low spatial sampling rate, many effective filtering tools cannot be directly applied to passive seismic data.
In this paper we propose a processing technique to address the above difficulties and allow suppressing the effects of transient anthropogenic noise on passive seismic attributes. Data from a test survey acquired at an oil and gas field in Voitsdorf, Austria are used to demonstrate the technique.

Passive seismic data set

In this study we analyse a 60-minute time window extracted from a survey line running north-south across two reservoir sections of the field. The line continuously recorded the natural seismic wave field during the night of March, 30th, 2008 using 46 3-component broadband seismometers deployed at 250 m spacing.

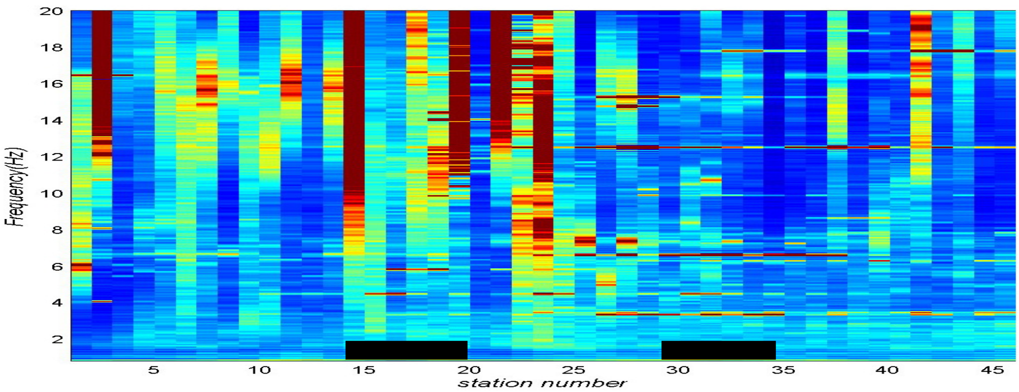
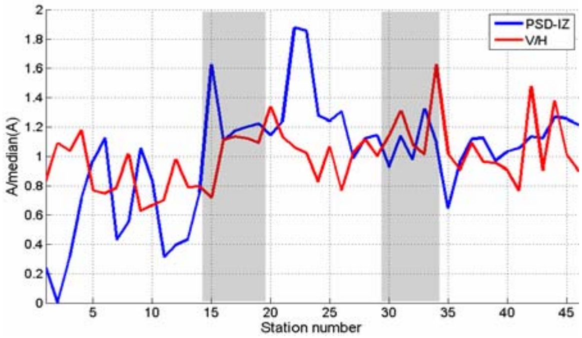


Figure 1 *Spectrograms of the data along the line. Reservoir locations relative to the line are marked as black rectangles. No obvious low-frequency anomaly can be observed above the reservoirs.*

Amplitude spectra of the vertical component recorded at all stations along the line are plotted side by side in Figure 1. The relative locations of the reservoirs are marked as black rectangles. Spectral amplitudes within the low frequency range (1-6Hz) do not show obvious anomalous values above the reservoir locations as expected.
Two spectral attributes (V/H and PSD-IZ) that are commonly used to aid data interpretation have been derived from the spectra in Figure 1 and are displayed in Figure 2. Detailed description of V/H and PSD-IZ can be found in Lambert et al. (2009).

Figure 2 V/H and PSD-IZ attribute profiles. The data have been normalized to their mean value. Both profiles show no obvious anomalies at the reservoirs locations (shaded rectangles). A possible reason for the poor result is the effects of transient noise contaminated in the data.



According to the authors the values of these attributes are supposed to increase above reservoir locations. However, the attribute profiles in Figure 2 do not convincingly demonstrate the claim. Since Voitsdorf oil and gas field is located within a culturally noisy environment, it is known to be influenced by traffic and producing activities in the vicinity. A low signal to noise ratio is therefore a possible explanation for the poor result (see discussion about the effects of anthropogenic noise in Hanssen and Bussat (2008)). In the next section we propose a processing technique that we found useful to suppress the effects of transient anthropogenic noise on passive seismic attributes.

Attribute sections and noise filtering

Spectral attributes are usually computed from the averaged spectrum of the data, so only one attribute value is calculated for each recording station (Lambert et al., 2009). Here we propose computing attributes semi-continuously over time. This is implemented by shifting a short time window through the data length by a given time step. At each step an attribute value representing the time window is calculated. As a result, a 2D attribute section is generated for the survey line showing the variation of the attribute in both time and space. The benefit of this approach is that consistent trends on the section can be easier to recognize. Moreover, 2D filtering techniques can be applied to the attribute section to reduce noise effects.

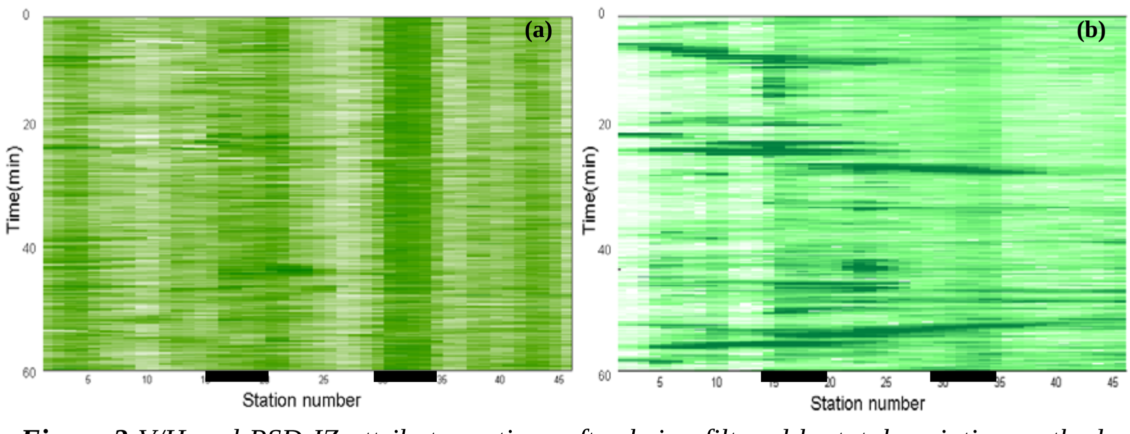


***Figure 3** V/H and PSD-IZ attribute sections after being filtered by total variation method. High amplitude vertical trends on V/H section (a) nicely match with the reservoir locations. PSD-IZ section (b) is dominated by transient noise (sub horizontal trends).*

Figure 3 shows V/H and PSD-IZ attribute sections generated from the data using a 10-second moving time window advanced by 2-second time step. The sections have been filtered by total variation method to remove strong but randomly distributed points. Interestingly, the V/H section (Fig. 3a) shows two vertical high amplitude trends associated with the reservoir locations that were not visible from the V/H profile in Figure 2.

Unlike the V/H section, the PSD-IZ section (Fig. 3b) is dominated by several high amplitude transient events spreading across the survey line. These transients are most probably caused by the traffic nearby (with estimated apparent velocities of around 100 km/h).

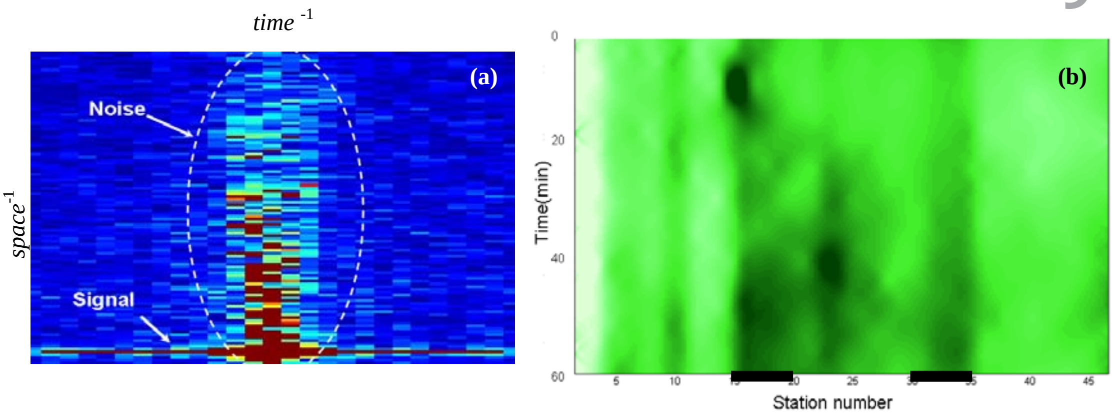


Figure 4 *F-K filtering of the PSD-IZ section in Figure 3b. Signal and noise are well separated on F-K domain (a). After F-K filtering, PSD-IZ section (b) shows a better match between high amplitude trends and the reservoir locations (black rectangles).*

Assuming that hydrocarbon related signals are local and quasi-stationary with time, the signal and the noise should have distinctive trends in the F-K domain. The F-K transform of the PSD-IZ section is shown in Figure 4a. Indeed, the transient and the stationary events are clearly separated into sub vertical and horizontal trends. After the application of an F-K filter the transient noise on the PSD-IZ section has been effectively reduced as shown in Figure 4b. It can be observed that vertical high amplitude trends on the PSD-IZ section in Figure 4b are better matched with the reservoir locations compared to the PSD-IZ profile in Figure 2.
Note that the use of attribute values instead of recorded time signals is the key that allows the application of F-K filter (and other 2D filters such as Radon). In this case the filtering is rather like an image processing to remove certain linear trends than the traditional F-K filter used in active seismic to remove incidents with certain apparent velocities.
From the attribute sections representative attribute profiles can be generated by stacking the data in time. Figure 5 shows the stack V/H and PSD-IZ profiles, which can be considered as the same profiles in Figure 2 but without anthropogenic noise effects. It can be seen that the reservoir locations are now better indicated by high amplitude values.

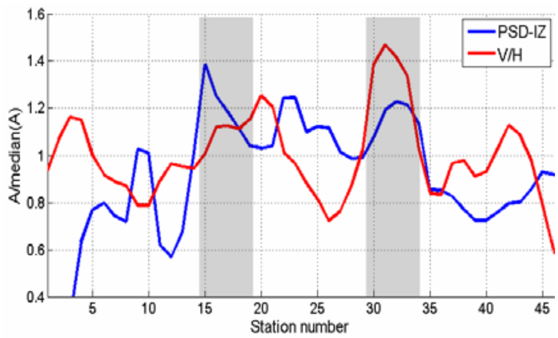


Figure 5 *Stack profiles generated from V/H and PSD-IZ sections in Figures 3a and 4b. The reservoirs (shaded areas) are better indicated by high amplitudes compared to the V/H and PSD-IZ profiles in Figure 2.*

Synthetic data

To investigate whether the observed low frequency anomalies can originate from the reservoirs themselves we carried out a forward modelling to simulate the process. The model domain is a 2D medium with seismic properties given by the known P-wave velocity distribution along the profile (Fig. 6a). Density and Poisson's ratio are set to constant values of 2000 kg/m3 and 0.25 respectively. Seismic tremor sources were set at the two known reservoir areas (Fig. 6a).
The tremor was generated by randomly distributed (in time and space) horizontal line sources with a finite length of 500 m. Such a source emits mainly P-waves perpendicular to the line and some weak circular S-waves at the two ends of the line. The time function of the body forces is a Ricker wavelet with 3 Hz central frequency.

At the surface, the particle velocities are recorded over time at 800 virtual receivers with a spacing of 20 m. The spectral attributes (PSD-IZ and V/H) are then computed from a 40 s time-window of the modelled signals and displayed along the profile (Fig. 6b).
It can be observed that the attribute sections and the stack profiles of the field data match well with the synthetic attribute values. The synthetic V/H profile in Figure 6b exhibits clear anomalous values above reservoir 1 and a lower but broader anomaly above reservoir 2. The synthetic PSD-IZ values are generally higher in the area between the reservoirs but not clearly resolve for individual reservoir locations. The same scenario can be observed on the attribute sections in Figure 3a, 4b and the stack attribute profiles in Figure 5.

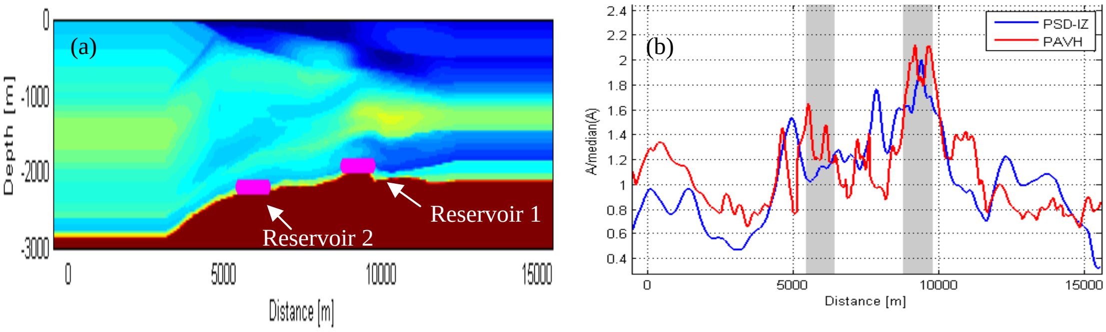


Figure 6 *The forward modelling uses realistic parameters of the field with low frequency sources put at the reservoir locations (a). V/H and PSD-IZ attributes of the synthetic data (b) nicely match the observation on the attribute sections of the field data in Figures 3a (V/H), 4b (F-K filtered PSD-IZ) and 5(stack profiles).*

Conclusion

We have demonstrated that by using attribute sections we bring in a new dimension (i.e. time) for data analysis. Consistent events in the data, be they signal or noise, are easier to recognize. The effects of random or transient noise, which have been a great concern for passive seismic method, can be suppressed from the attribute sections by applying different types of 2D filtering such as total variation or F-K.
The data set used in this study is influenced by anthropogenic noise. The spectra of raw data and their commonly used attributes could not reveal clear indications of the presence of HC reservoirs. V/H and PSD-IZ sections, after being filtered to reduce noise effects, show a good agreement between reservoir locations and high amplitude trends on the sections.
The characteristics of the anomalies found by attribute sections match well with the spectral attributes of the synthetic data generated by a forward modelling of the same area.

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