Noise suppression on geophone data using microphone measurements

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SUMMARY

Noise in the shallow part of a seismic section is very problematic. Quite often air-wave noise overwhelms data that is useful and important. Some types of this noise that consistently cause problems in imaging shallow seismic surveys are air-coupled ground roll, air blast, ground–coupled air blast, and wind noise. In this study, we attempt to use microphone recordings of air-waves (i.e. wind) to suppress air-wave noise on geophone data. We conducted a four-component (3C geophone and a microphone at each receiver station) seismic line in the Pike's Peak heavy oil field, Saskatchewan. Initial investigations find a strong air-wave generated by the vibrator source.

INTRODUCTION

Various types of noise can certainly overwhelm subsurface reflection signals. This is particularly true when the seismic survey is attempting to image a shallow target or when the noise source is near the geophone receivers. In the marine case, recording hydrophone data along with geophone data can attenuate ambient noise. The hydrophone data is used to suppress air–associated noise on geophone data. Similarly, for the land case, we propose the use of microphone data to suppress air-associated noise on geophone data. In addition, we suggest designing a geophone with an attached microphone to reduce noise on the geophone data. This will serve to attenuate unacceptably high wind and wind–coupled noise that can shut down seismic acquisition operations.

NOISE OVERVIEW

When using a surface source, such as dynamite or a vibrator, the air-wave may be significant and problematic. An air-wave can couple into the ground to generate a Rayleigh wave when the wave's phase velocity is close to the speed of sound in air, about 332 m/s. Ground roll can also generate an air–wave when its velocity is close to that of sound in air. In shallow target seismic surveys, these noises (ground roll and air-blast) consistently overwhelm the usable data.

Winds arise from pressure differences in the atmosphere. They translate into geophone motion via wind pressure on the geophone case or through an intervening medium that vibrates. When winds reach a certain velocity, there is too much noise generated on the geophone to continue recording data. Actively filtering some of this noise could, perhaps, extend seismic operations into more windy conditions that currently cause acquisition to shut down.

PIKE'S PEAK MICROPHONE/GEOPHONE SURVEY

The Pike's Peak data was acquired along a 3.8 km line. The vibroseis sources were recorded into conventional vertical component geophone arrays, single 3C geophones, and single microphones. The source interval was 20 m recorded on the station while the receiver interval for the geophone arrays and microphones was 20 m. A 10 m receiver interval was used for the 3C geophones. An ARAM24 seismograph was used by Veritas DGC Land to record this unique data set in SEG-Y IBM format at a 2 ms sample rate for a total record length of 20 s. There were 191 source points spaced 20 m apart that used 2×25000 kg Hemi 44 vibrators straddling the source location flag, resulting with the source point being positioned on the station. Each source point consisted of 4 sweeps that were individually recorded. Refer to "Acquisition and processing of the Pike's Peak 3C-2D seismic survey" by Hoffe et al. of this volume for a complete description of this survey.

Figure 1. Several recording stations and a vibrator source used in data acquisition.

Figure 2. The vertical geophone (left) and the geophone-microphone motion sensor (right).

FILTERING PROCEDURE

Air pressure on the microphone is related to ground motion on the geophone by direct vibration of the geophone or via ground coupling. Similarly, ground motion can vibrate the air and geophone case and thus the microphone. By cross correlating geophone and microphone data, the amount of phase mismatch can be estimated and an appropriate filtering procedure can be developed. The two simplest cases are when both data sets are in phase with each other or when they are 180° out of phase. If they are in phase, then filtering occurs with a simple subtraction. If they are 180° out of phase, then filtering occurs with a simple addition.

A NOISE REDUCING MULTI–SENSOR

The simplest 2 element, air-wave reducing instrument could use a microphone in close proximity to the geophone with its output recorded separately. These recordings could then be used later to filter the geophone data. This is the approach taken currently. Figure 3 shows a schematic design of such a tool and the actual tool used to acquire the data sets discussed in this work. The actual field tools consisted of 6 OYO 30-CT 10 Hz geophones, microphones with a Panasonic WM-54BT electret condenser element that has a frequency range of 20-16000 Hz, and Litton LRS-1033 10 Hz 3C geophones. The OYO geophones and Panasonic microphones were laid out with 20 m spacing while the Litton 3C geophones were laid out with a 10 m spacing. Figure 4 shows that the standard microphones used in the motion sensor have a remarkably stable response up to 10000 Hz with only minor deviation beyond that.

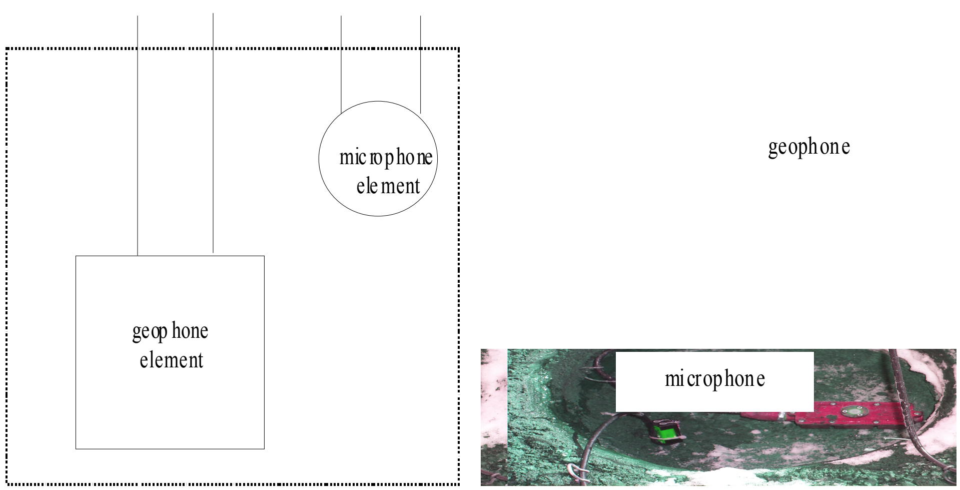

Figure 3. Two channel motion sensor schematic and the actual motion sensor used in field.

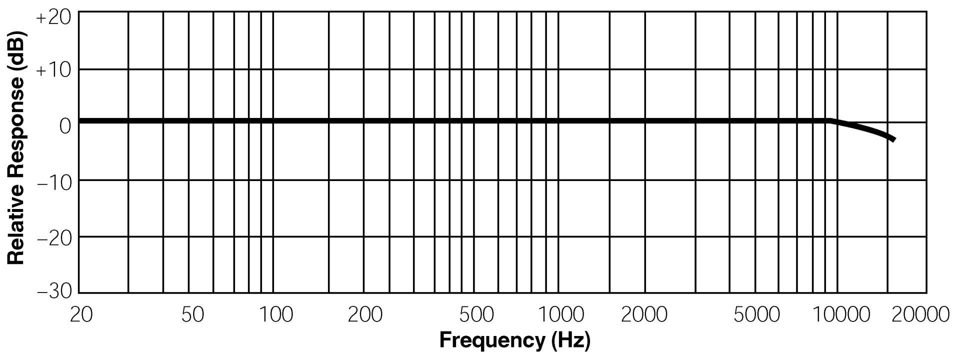

Figure 4. The relative frequency response of the microphones used in the motion sensor.

Alternatively, a microphone could be built into the geophone case to give air pressure measurements at the geophone. These measurements could be recorded separately as a two–channel geophone or with a 3–C geophone as a 4–channel record. More interestingly, we could design a motion sensor that actively reduces noise. The microphone could be used in series or parallel with the geophone and the air pressure noise could be removed from the geophone output in real time. Theoretically, this involves the microphone output resisting the air–correlated noise values from the geophone.

REPRESENTATIVE RESULTS

Figure 5 through Figure 14 show a representative set of results to date on this research. A raw geophone shot record from the decimated vertical component is shown in Figure 5. Also shown is the microphone record for the same shot. Notice that the response of the microphone record seems to be much higher in frequency.

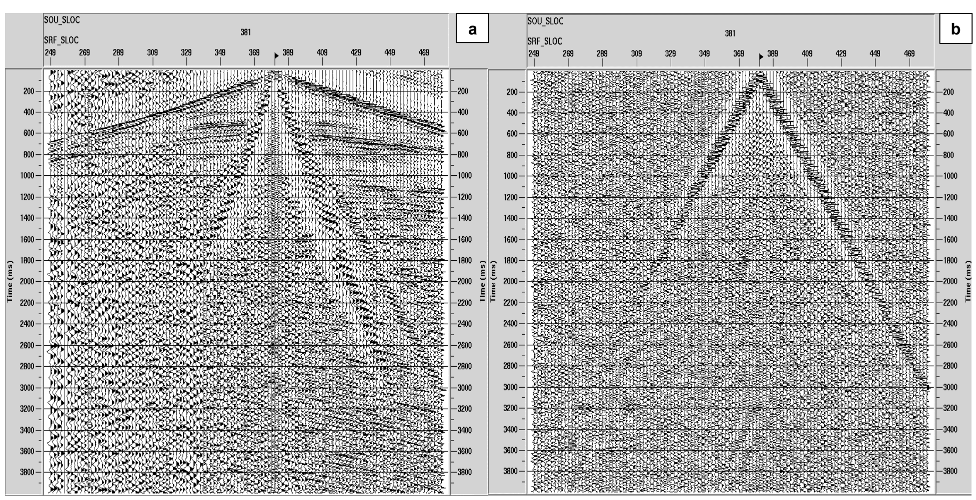

Figure 5. (a) Raw vertical geophone record. (b) Raw microphone record. Both from shot 7.

The F-K spectra of the above records are shown in Figure 6. Notice that there are significant signal responses for low frequencies on the microphone record. These low frequency responses on the microphone record may be useful in designing noise removal filters since the low frequency ground roll can be air-coupled.

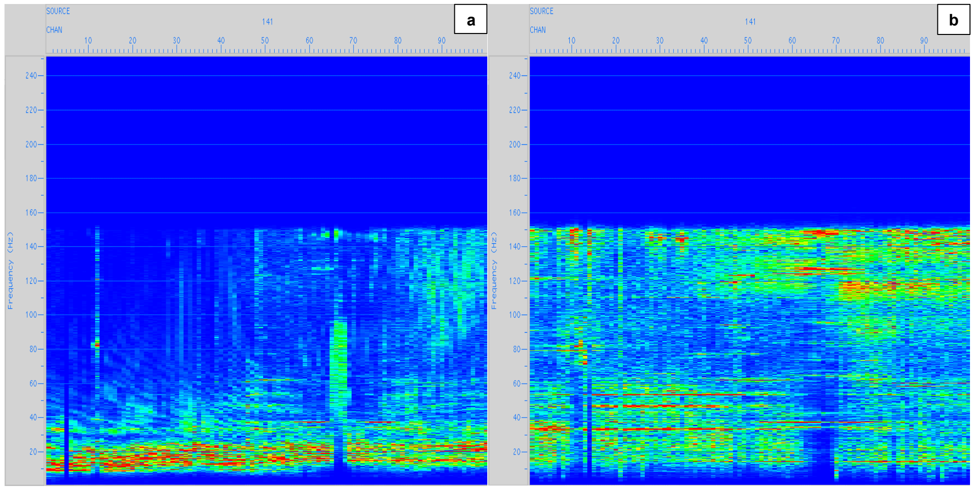

Figure 6. (a) F-K spectrum for geophone data. (b) F-K spectrum for microphone data.

A series of filter tests are conducted on the geophone and microphone data with two results shown in Figure 7 and Figure 8. Figure 7 shows both data sets with a 5-10-20-25 Hz bandpass filter applied. This filter panel shows that there are usable signals in the low frequency range of 10-20 Hz and that they may be of use if ground-roll and air-blast can be effectively suppressed. Figure 8 is included because it shows an unexpected signal that is of particular interest. When a 25-30-40-45 Hz bandpass filter is applied to the data sets, the signal is quite deteriorated on the geophone record but the same is not true for the microphone record. In this case, a clear and repetitive noise cone, with a constant time lag, appears on the microphone data. Given that shot 7 was recorded near an active pump jack, this signal is interpreted as pump jack noise and can be removed using some type of predictive deconvolution process since the prediction lag can be quite easily computed. Further studies will have to be completed before a general claim about the nature of pump jack noise can be made. For this particular data set, it can be said that the noise from operational pump jacks manifests itself as a repetitive noise cone in the bandwidth of 30-40 Hz.

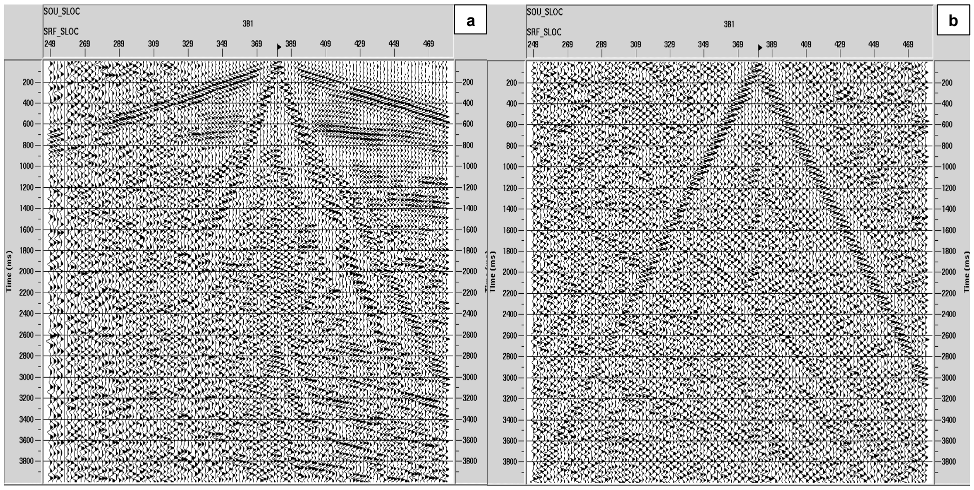

Figure 7. Geophone data (a) and microphone data (b), both with a 5-10-20-25 Hz filter.

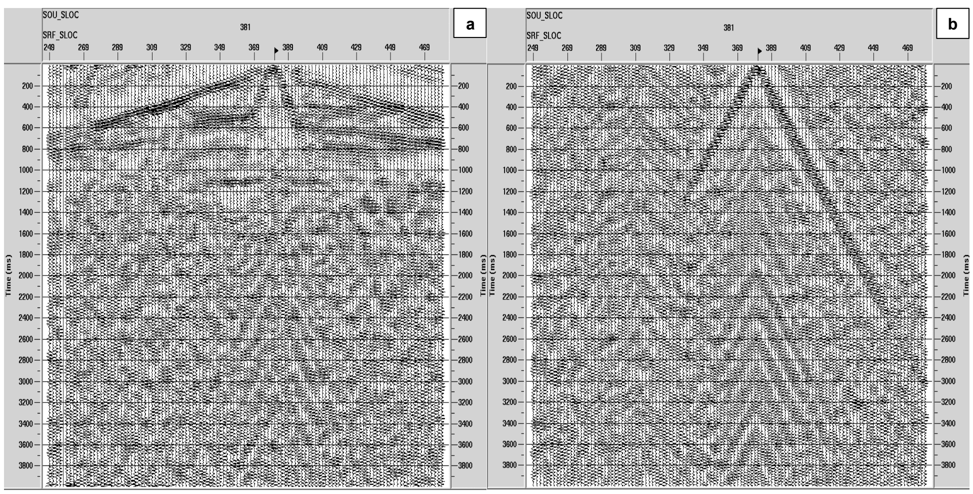

Figure 8. Raw vertical geophone (a) and microphone data (b), both with a 25-30-40-45 Hz band pass filter applied. Note that these frequencies are quite deteriorated and it appears as if the pump jack noise is coming through.

After these preliminary investigations, the microphone data is geometry corrected; treated as P-P data, and then it is pushed through a brute stack flow (see Table 1) in ProMAX.

Table 1. Processes in the microphone brute stack ProMAX flow.

Brute Stack Processing Flow

1. input geometry corrected microphone data
2. normal moveout correction
3. bandpass filter
4. trace muting
5. automatic gain control
6. cdp/ensemble stack

This stack is shown in Figure 9 and it seems to be lacking any lateral coherence. All that is shown is a random set of traces with no lateral continuity from trace to trace. Figure 11 shows a geometry corrected microphone shot record that is input into this stack and its corresponding F-K spectrum. From the F-K spectrum, it is seen that there is a severe aliasing problem with the frequencies on the microphone record and this is why the brute stack is of such poor quality.

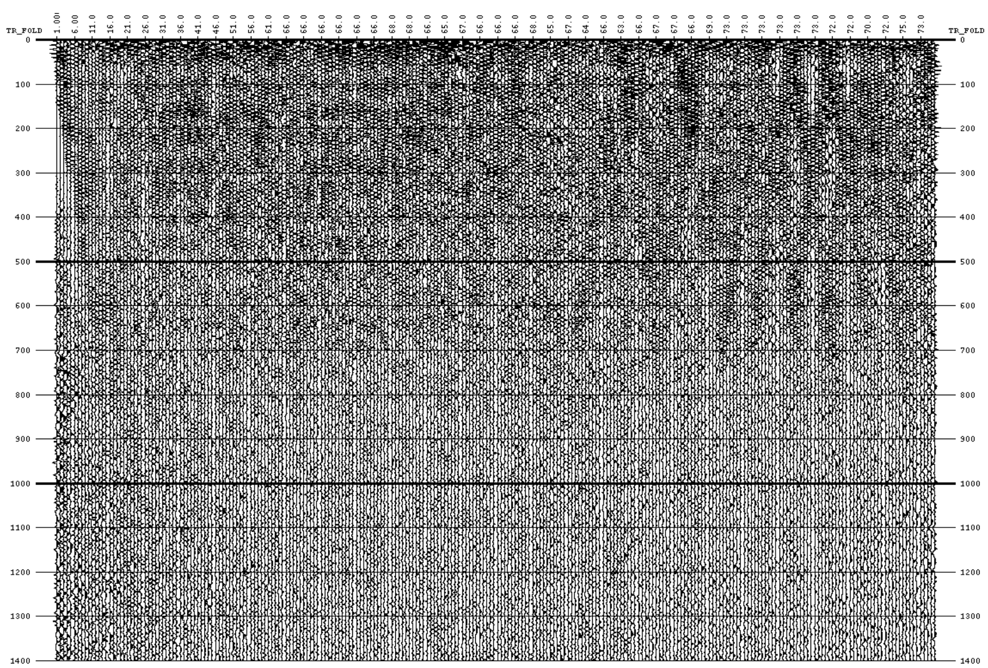

Figure 9. Brute stack of microphone data.

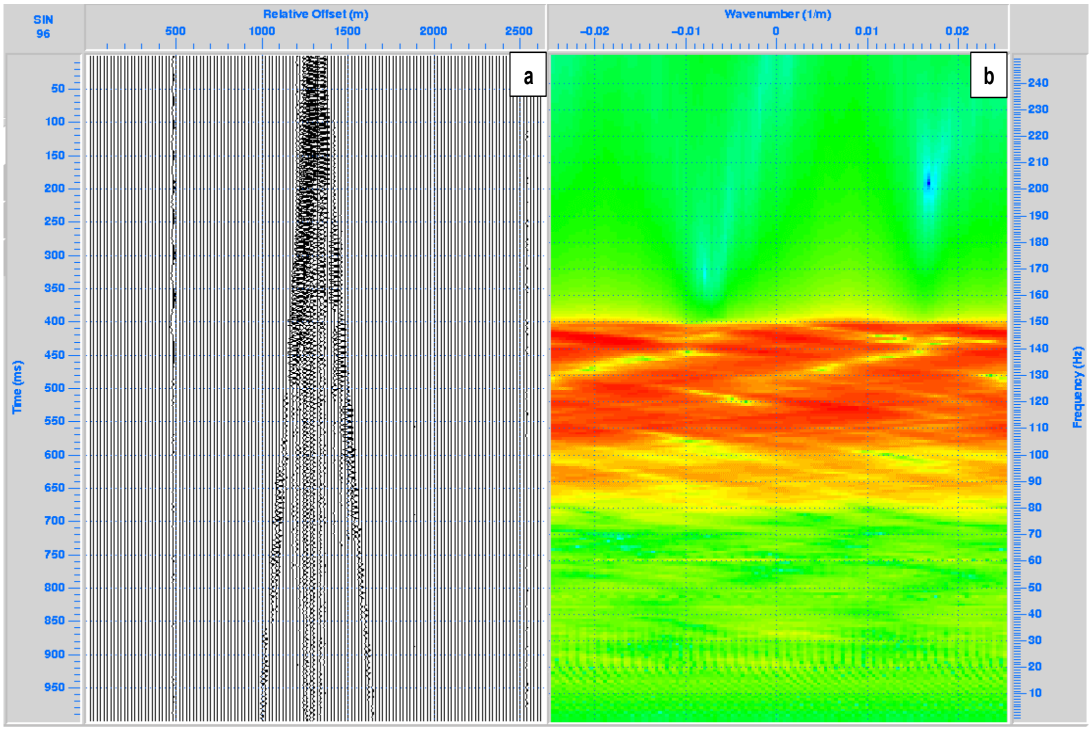

Figure 10. (a) Microphone data with geometry applied. (b) The F-K spectrum of the microphone data with the geometry applied. Note that there is a severe aliasing problem.

The next avenue of research is to investigate whether microphone data can be used to filter air-coupled noise out of geophone records. In an ideal case, the air-coupled noise in a seismic section would be removed by subtracting the microphone record from the geophone record. This, however, is not the case. Figure 11 (a) shows the cross-correlation of the microphone data and geophone data for trace 1 of shot 7. The largest peak occurs at a time of 6 ms and this time lag implies a phase mismatch between the data sets. Further phase investigations are conducted and Figure 11 (b) indicates that a $\pi/2$ phase mismatch exists. This phase rotation must be performed before attempting to filter the seismic data by subtracting the microphone record from it. The microphone data is rotated by $\pm\pi/2$ and then used in an attempt to filter the geophone record. These results are shown in Figure 12. It is evident that for this trace a simple addition or subtraction process is not an ideal filter. This trace-by-trace phase rotation analysis and addition/subtraction process must be conducted on an entire shot record to fully assess if it is effectively filtering the geophone record.

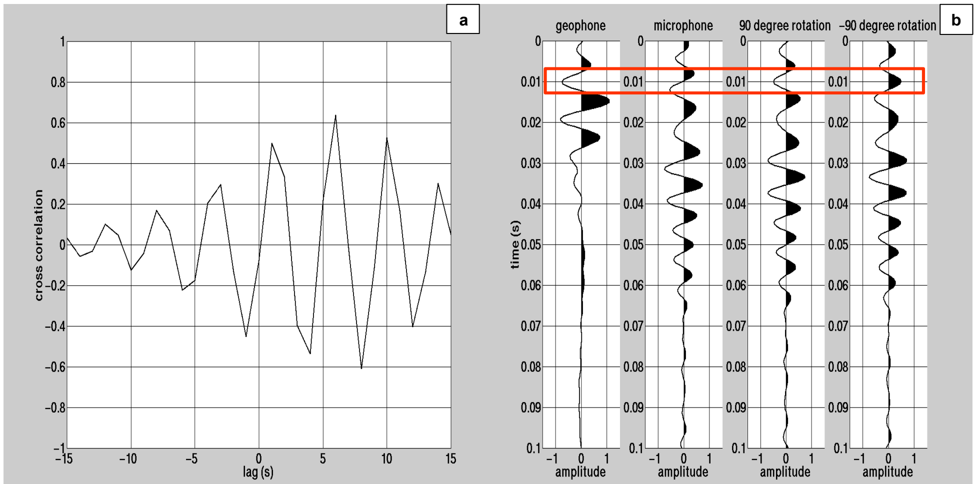

Figure 11. (a) Geophone and microphone data cross correlation for trace 1 of shot 7 (b) The geophone, microphone, and phase rotated data. Note the |π/2| phase mismatch.

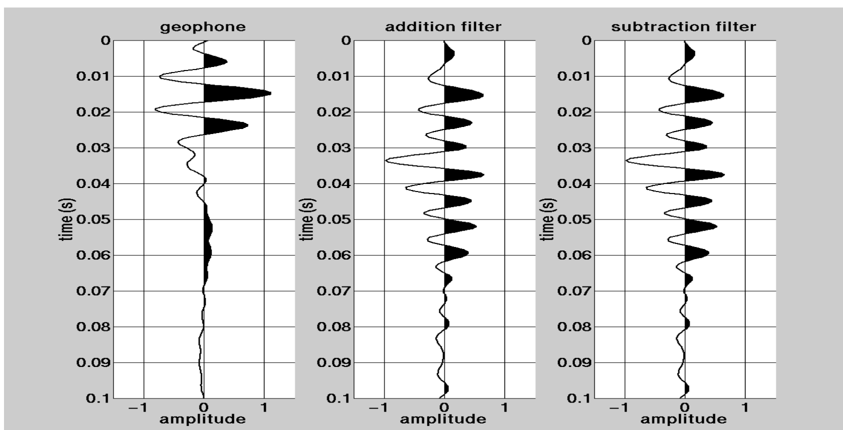

Figure 12. Raw geophone data, with the addition filter, and with the subtraction filter.

A more sophisticated mathematical approach may be necessary to fully utilise microphone data records. Figures 13 and 14 show some investigations into the nature of geophone and microphone signals. Using better spectral analysis tools, we attempt to uncover some fundamental relationships between signals recorded on microphone and geophone channels. A short time (i.e. windowed) Fourier transform is conducted on trace 1 of shot 7 for both the microphone and geophone data. The time variant nature of the signals is shown in Figure 13 (a) and (c) as amplitude versus time plots. Figure 13 (b) and (d) show that the windowed Fourier transform does a poor job trying to localise the signals in frequency and in time.

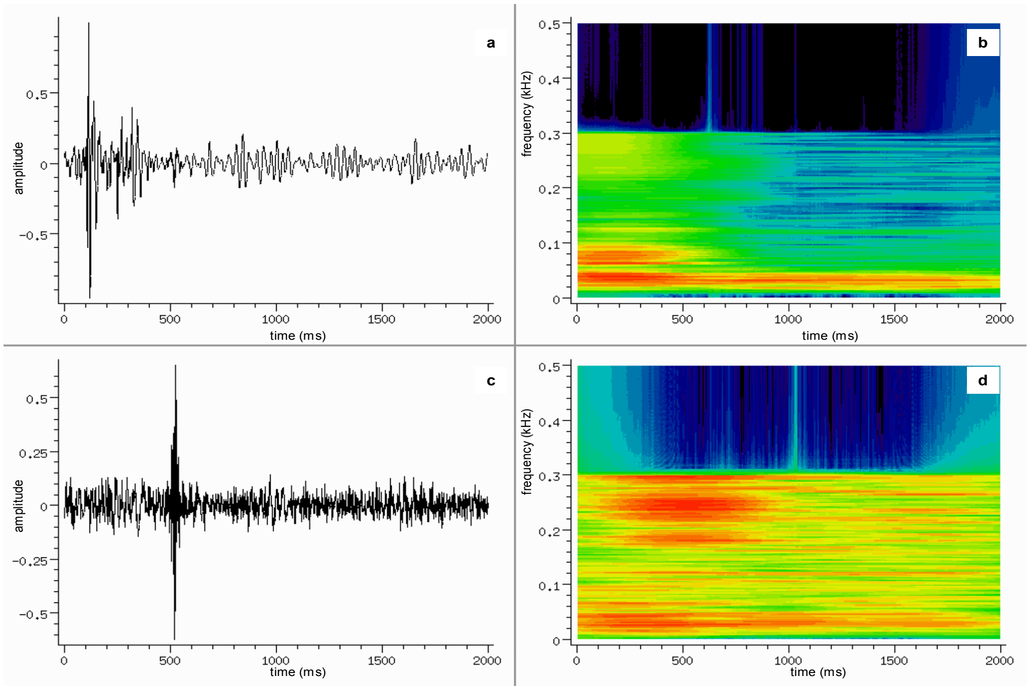

Figure 13. (a) The raw geophone data. (b) The short time Fourier transform of the geophone data. (c) The raw microphone data. (d) The short time Fourier transform of the microphone data.

Given that established spectral analysis tools are proving to be insufficient to characterise the relationship between the microphone and geophone data, a new approach is needed. The developing field of mathematical wavelet transforms may provide the tools necessary to uncover how geophone and microphone records relate. The basic discrete wavelet transform has good time localisation and poor frequency localisation for high frequencies. Conversely, it has poor time localisation and good frequency localisation for low frequencies. Seismic data usually contain frequencies in the 10-70 Hz range and this implies that a seismic section will contain mostly intermediate frequencies. To effectively process seismic data, there is a need for a frequency-time transform that can produce good localisation in frequency and time for all the intermediate frequencies in the data.

The matching pursuit decomposition of Mallat and Zhang (1993) is one type of frequency-time transformation that offers high frequency-time localisation for intermediate frequencies. In the matching pursuit decomposition, scaling, translating, and modulating a window function creates a set of basis functions. The basis functions are *frequency-time atoms* and if the window function is Gaussian then the atoms are called *Gabor atoms*. Mallat and Zhang show Gabor atoms provide detailed frequency-time localisation. These atoms form a redundant set and the best match to the input signal is found by projecting the atoms onto the signal and then computing the maximum. After this a residue is computed and this decomposition continues until the energy of the residue falls below some threshold. Chakraborty and Okaya (1995) use matching pursuit decomposition to identify four types of atoms that are useful in seismic signal analysis. The first type of atom is elliptical in shape with the major axis of the ellipse along the frequency axis. This represents events that are localised in time but posses an array of frequencies, and reflection events fall under this atom category. A second type of atom is also elliptical in shape but with the major axis lying along the time axis and this represents events that have long time duration and narrow bandwidth (i.e. low frequency surface waves). There is a third atom that is circular in nature and it represents events that have only one or two frequencies and are present for only a short period of time. The final type of atom is a relatively long streak in the time direction and represents a monotonic frequency that occurs over a long time duration, such as 60 Hz power line noise. Each of these types of atoms occur in the matching pursuit decompositions shown in Figure 14.

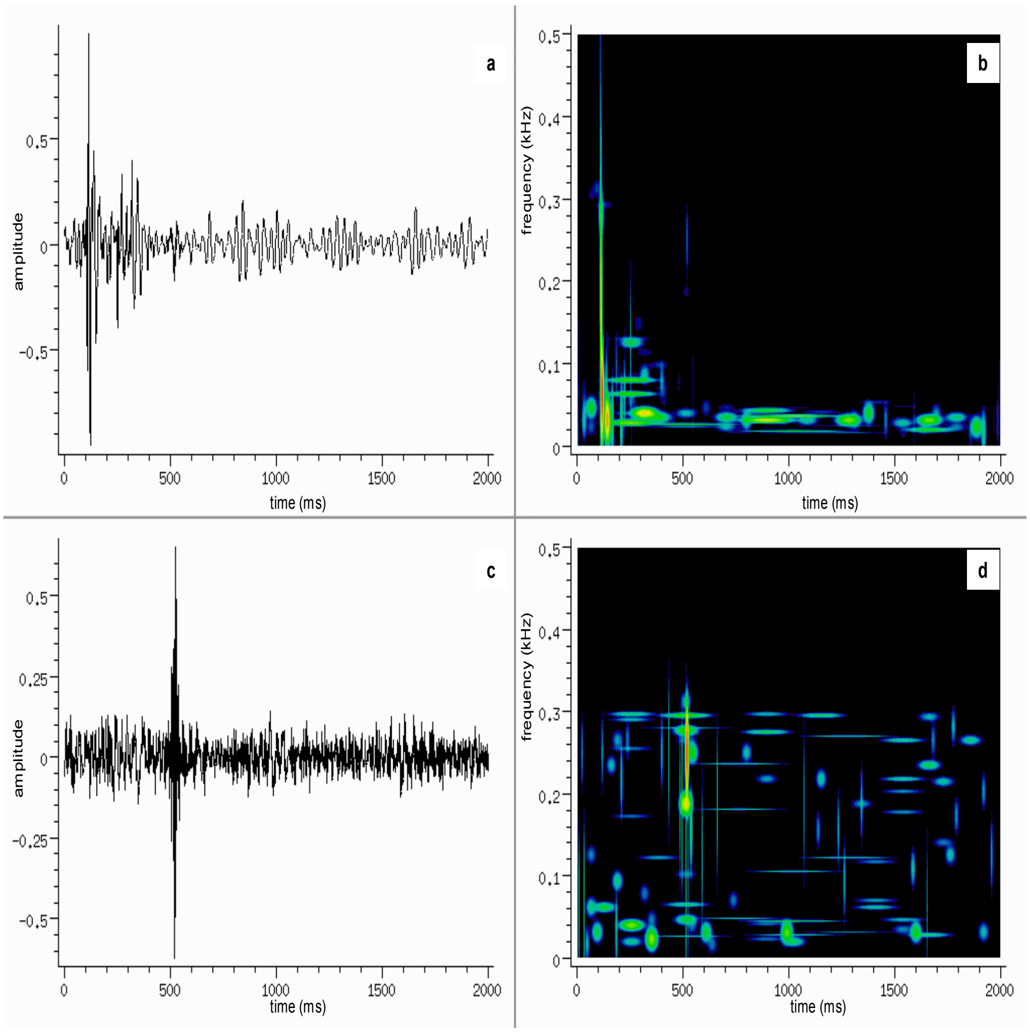

Figure 14. (a) The raw geophone data. (b) The matching pursuit decomposition of the geophone data. (c) The raw microphone data. (d) The matching pursuit decomposition of the microphone data.

CONCLUSIONS AND FUTURE DIRECTIONS

The preliminary results from analysing the microphone data set are quite encouraging. There is correlation between what we consider air–wave noise on geophone data and various events in microphone data. A trace-by-trace phase analysis will be done so that an entire shot record can be filtered using the subtraction method discussed earlier. It is hoped that this may offer better lateral continuity on the brute stack. Also to be attempted is a simple air-blast removal using a moveout function determined from the microphone data. Future directions include developing filtering methods that use sophisticated mathematical tools to map between geophone and microphone data. Investigations show that the mapping of a single seismic trace to a 2-D frequency-time space using the matching pursuit algorithm offers improved signal decomposition into its principle spectral components. In particular, seismic reflections and surface waves with different arrival times will separate in the frequency-time plane using this method more readily than with standard Fourier based techniques. This may allow for a deeper understanding of the spectral behaviour of seismic and microphone data. Then it may be possible to use the microphone data to filter surface waves from the geophone data using polygonal (i.e. pie-slice) filters in the 2-D frequency-time domain.

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