New VSP wavefield separation methods

Satinder Chopra, Vladimir Alexeev and Joanne Lanteigne
Core Laboratories Reservoir Technologies Division, Calgary

2004 CSEG National Convention

VSP wavefields consist of a superposition of the downward and upward travelling (or simply downgoing and upgoing) wavetrains, and all the unwanted signals we call noise. Both the downgoing and upgoing wavetrains are useful, but need to be separated before they can be studied and utilized. Different methods have been used for VSP wavefield separation over the last four decades, keeping in mind the time variant nature and the signal-to-noise ratio of the wavefield. The most commonly used methods in production runs so far have been (a) *median filtering (b) f-k filtering.*

The median filtering method is used to isolate downgoing (by first aligning them, applying a median filter and shifting back), and then subtracting the separated downgoing wavefield from the total wavefield to get the upgoing wavefield. The common f-k transform technique implicitly model the input data as a sum of a number of plane waves and transforms the VSP data into the f-k domain. In this domain the downgoing events reside in the positive wave number quadrant and the upgoing events in the negative quadrant. The upgoing wavefield is separated by operating on the positive quadrant events. The inverse Fourier transform yields the upgoing wavefield. Similarly, the downgoing wavefield can also be separated. Figures 1 and 2 show the aligned upgoing VSP wavefields after separation using the median and f-k methods respectively on a zero offset VSP. Clearly, the f-k method does not do a satisfactory job.

Apart from this the following methods are also reported in the literature, though not commonly used in production runs and so do not form part of the discussion here.

(i) K-L filtering (Hinds et al 1996)

(ii) τ-p filtering (Hu and McMehan 1987, Hardage 1992)

(iii) Parametric separation (Esmersoy 1990, Leaney 1990)

In this method the decomposition of multicomponent VSP data into its dominant P and S wavefields is formulated as a parametric inversion, where each wavefield is modeled as it Fourier components and by two frequency-independent parameters – apparent slowness and polarization angle. A reliable transform of the spatial variable requires a well–sampled sequence of amplitudes over which the trace-to-trace moveouts should be constant. Sharp changes in moveout result in smearing and a consequent loss of spatial resolution.

In addition to these methods two new methods are discussed here and are called

1. Optimisation inversion method
2. LIFT method

Optimisation inversion method:

In this method, as the first step the different wavetrains (i.e. upgoing, downgoing, etc) that can be seen on the VSP shot record(s) are identified and marked. Figure 3 shows a shot record with the component wavetrains marked. This becomes the model wavefield. After selecting and subtracting these waves, the residual wavefield may contain noise and also some regular wavetrains which could not be extracted from the total wavefield. This residual wavefield, in fact, shows the quality of separation and adequacy of the model to real data. This residual wavefield signal is iteratively extracted from the residual wavefield. This is carried out in a few iterations till the difference between the total and the modeled wavefields can no longer be minimized. All these operations are done in the time domain. This method has been referred to as optimization inversion and has been used to effectively separate wavefield components (Chopra et al 2003, Chopra et al, 2004).

Figure 4 shows the aligned upgoing VSP wavefield for the same zero offset VSP using the optimization inversion method. Some of the reflection cycles are seen separated distinctly with more continuity. This would aid in getting a more realistic corridor stack.

LIFT method:

LIFT is an amplitude friendly technique that is used to attenuate noise and multiples in the seismic data (Choo and Sudhakar, 2003). Signal and noise are modeled and then the noise component is removed in an adaptive non-linear manner. The methodology assumes importance when amplitude preservation is critical for such applications as AVO inversion. This method has been used very effectively to separate out ground roll, air blast, multiples and other types of noise from seismic data (Dewar et al, 2003).

LIFT workflow has been applied to VSP data and the results shown here exhibit how effectively it separates the component wavefields.

Figure 5 shows the upgoing VSP wavefield separated using LIFT. This exhibits all the necessary reflection detail in the data. The reflections have a higher resolution, continuity and stand out much more compared with the other methods.

Figures 6 to 9 show the corridor stacks generated for the upgoing VSP wavefield for each of the methods used for wavefield separation. The following are some conclusions:

(a) Corridor stacks for optimization inversion and LIFT methods are seen to have much higher resolution than median and f-k methods. A cycle-by-cycle reflection comparison confirms this.

(b) LIFT separation method yields a corridor stack that matches the seismic better in terms of amplitude preservation. Notice the equal intensity doublet (red, in the middle of the section) that overlays a strong doublet (on the sides), as opposed to the uneven amplitudes found in the corridor stacks produced by the other methds.

(c) LIFT and optimization inversion methods are more accurate than other methods available in the industry.

References

Choo,J., Sudhakar,V.. 2003, LIFT: a new seismic processing technique to LIFT noise and multiples, 2003, CSEG/CSPG Joint National Convention.

Esmersoy,C., 1990, Inversion of P and SV waves from multicomponent offset vertical seismic profiles, Geophysics, p39-50.

Leany,W.S., 1990, Parametric wavefield decomposition and applications, 60th Int'l SEG meeting, San Francisco, p1097-1100.

Hu.L.-Z and McMechan,G.A., 1987, Wavefield transformation of vertical seismic profiles, Geophysics, V52, p307-321.

Hardage, B.A. Crosswell seismology and reverse VSP: Geophysical Press.

Chopra,et al,2004: In Press

Dewar,J.,Downton,J.,& Larsen,G., Michelangelo, Seismic and Seeing What's There,CSEG RECORDER, November 2003.

Hinds,R.C., Anderson,N.L., Kuzmiski,R.D., VSP Interpretive Processing: Theory and Practice, SEG Pblication, 1996.

Acknowledgements

The authors also thank Core Lab Reservoir Technologies Division for its approval to publish this work.

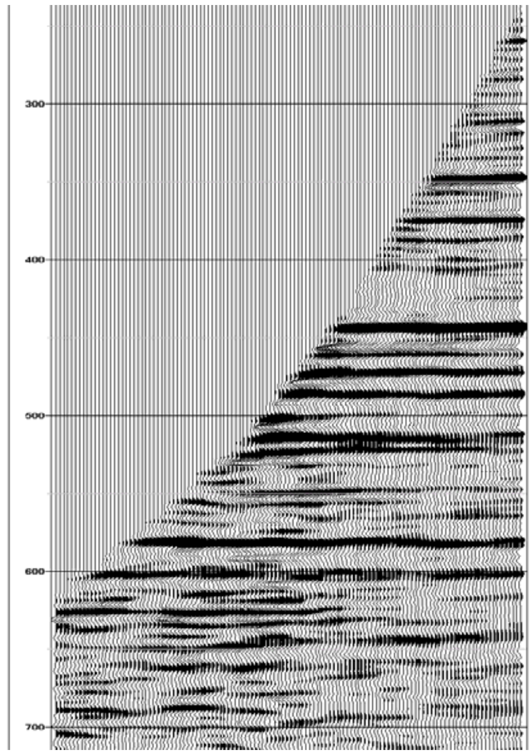

Fig.1 : Aligned upgoing VSP wavefield separated using median filtering

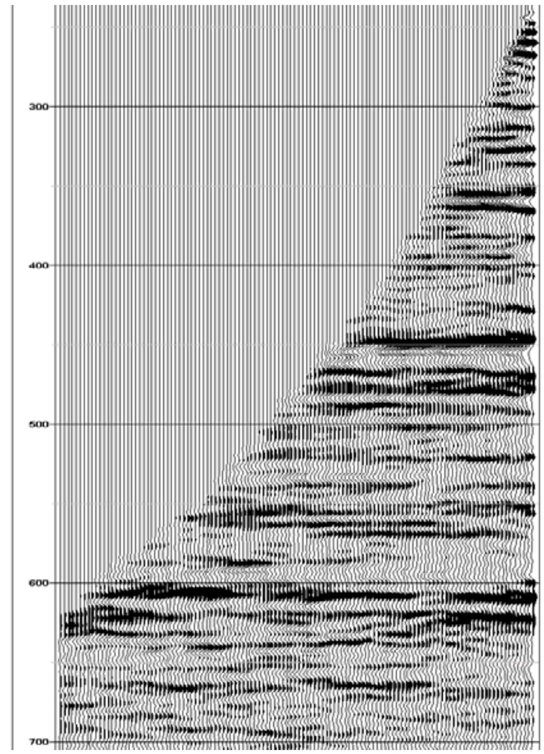

Fig.2 : Aligned upgoing VSP wavefield separated using f-k filtering

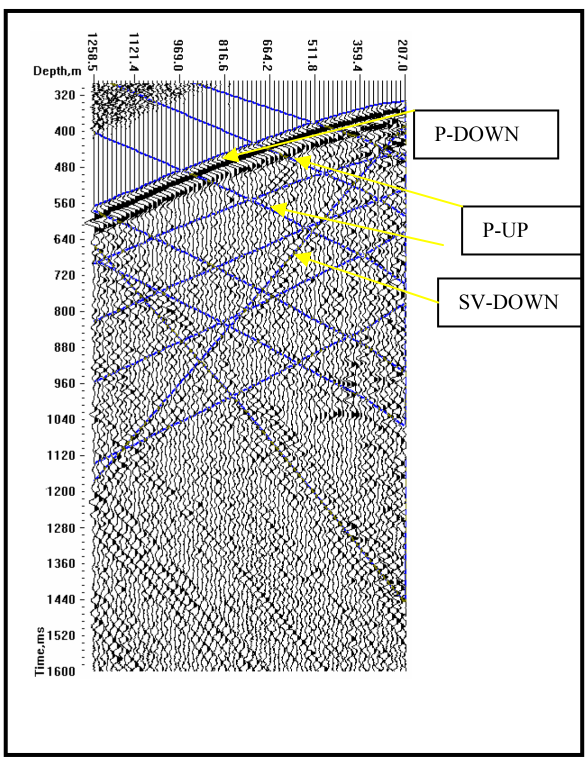

Figure 3: Description of wavefields on a VSP record

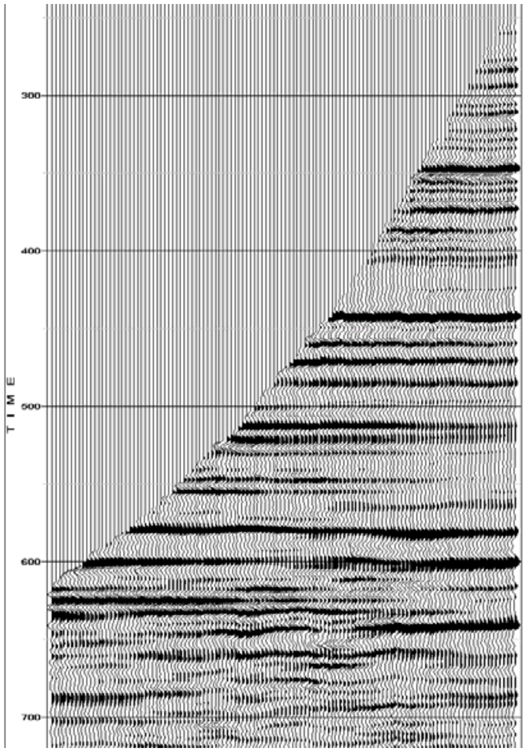

Fig.4 : Aligned upgoing VSP wavefield separated using optimization inversion

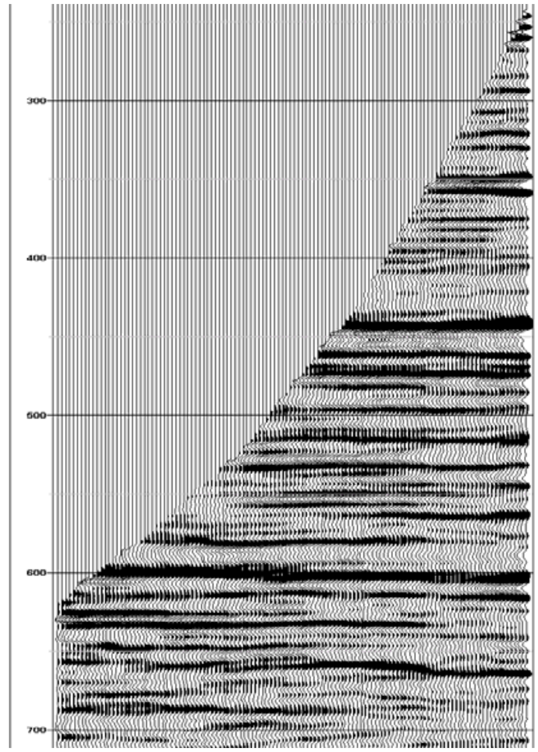

Fig.5 : Aligned upgoing VSP wavefield separated using LIFT

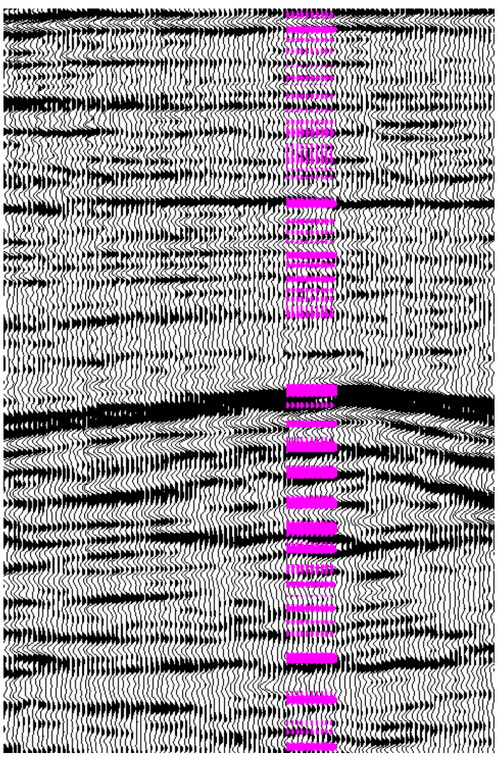

Fig 6 : Correlation of corridor stack (median filtering) with seismic

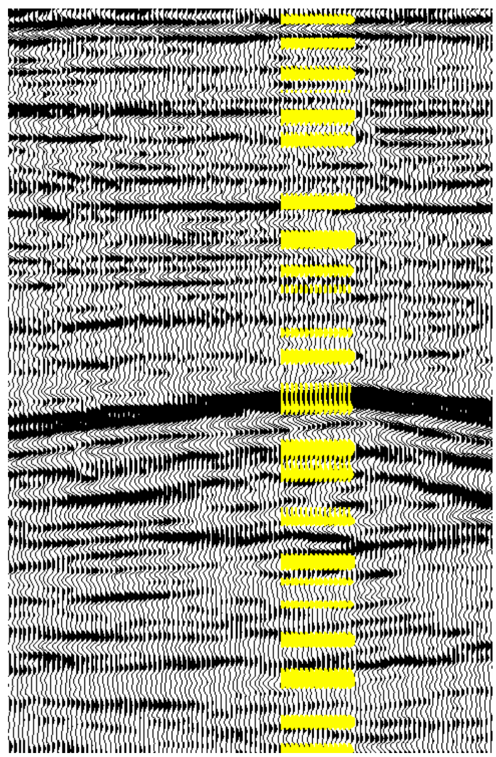

Fig.7 : Correlation of corridor stack (f-kfiltering) with seismic

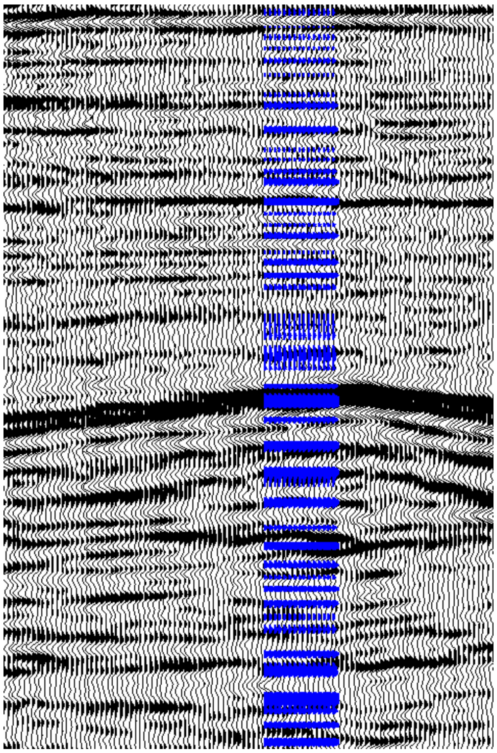

Fig.8 : Correlation of corridor stack (optimization inversion) with seismic

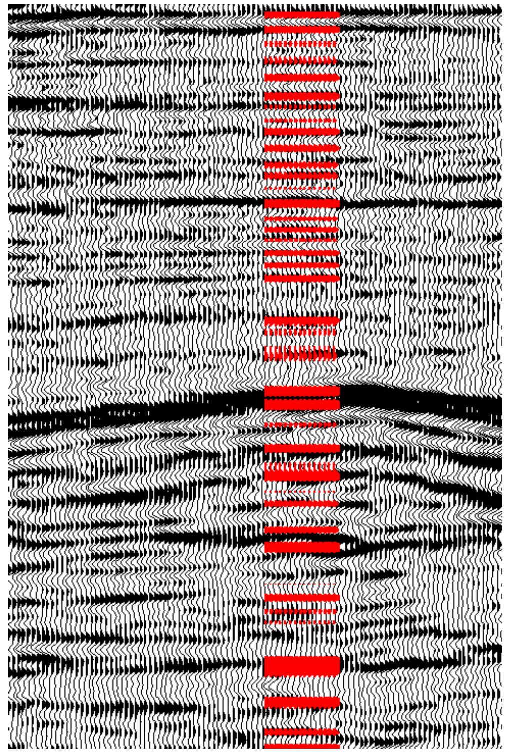

Fig.9 : Correlation of corridor stack (LIFT) with seismic