The impact of multiple suppression on vertical cable data imaging

Hejie Wang, Alexander Druzhinin and Xiang-Yang Li, EAP, British Geological Survey*

Summary

We present a special processing scheme for vertical cable seismic (VCS) data and show its impact on common-receiver data imaging. The key steps are wavefield separation and multiple suppression prior to migration. The latter includes common-shot demultiple filter to attenuate receiver ghosts, predictive deconvolution, and the Radon velocity filter. VCS velocity analysis is performed to obtain the velocity function. The zero-offset Kirchhoff time migration is then applied to NMO-corrected sections. Application to field data from the North Sea shows that this procedure results in enhanced VCS migrated sections.

Introduction

The VCS represents an alternate method to acquire 3-D seismic data. In this method, hydrophone cables are vertically deployed in the water column. This technique of data acquisition has been demonstrated as a potential method for exploration of different types of prospects (Havig, 1996; Krail, 1993; Leach, 1997; Ikelle and Wilson,1999), especially for complex structure imaging due to the high data quality and a full azimuthal coverage of the target.

As with other marine exploration methods, water-column multiples are still one of the most troublesome forms of noise in VCS data. We take the advantage of the unique VCS geometry and design a special processing scheme for wavefield separation and multiple removal. The task is to examine the effect of multiples on VCS velocity analysis and data imaging.

Processing scheme

1. Wavefield separation

We apply a common-shot differential equation-based filter by Wang *et al.* (1999) to separate up- and downgoing waves. This method uses a finite-difference algorithm to solve the filtering equation in the time-space domain. The filter parameters represent a set of user-specified dominant frequencies and apparent velocities, and can vary at every temporal and spatial point.

2. Multiple suppression

Firstly, we develop a common-shot demultiple filter in the (tau-p) domain to attenuate receiver ghosts. For the receiver located at the sea bottom ($z = h$), the upgoing wave $u_U(t,h)$ and downgoing wave $u_D(t,h)$ should have the same arrival time $t = \tau$. We construct the (tau-p) transform pair $u_{U,D}(t,z) \leftrightarrow u_{U,D}(\tau,p)$ by stacking along the slant line $t = \tau \pm p(z-h)$ (Zhou and Greenhalgh, 1994). Using an N-sample time window of M traces in the (tau-p) domain, we define the following simple summation measure

$$A_{U,D}(\tau) = \sum_{i=-N}^{N} \sum_{j=1}^{M} |u_{U,D}(\tau + i\Delta\tau, p_j)| , \qquad (1)$$

where $\Delta\tau$ is the time sampling interval. Similar to Zhou and Greenhalgh (1991), we employ the form of the Buttworth gain function in the (tau-p) domain

$$g(\tau) = \frac{1}{\sqrt{1 + \left(\frac{A_D(\tau)}{\epsilon A_U(\tau)}\right)^n}}, \qquad (2)$$

where ϵ (≥ 1)is the multiple rejection parameter, and n is the parameter used to control the smoothness of the filter with value between 6 and 8. The function (2) is applied on a pixel by pixel basis to the data $u_U(\tau,p)$. $g(\tau) \ll 1$ where high-amplitude events (multiples) are present in the data $u_D(\tau,p)$ and $g(\tau) \to 1$ otherwise. The condition $A_D(\tau)/A_U(\tau) < \epsilon$ produces a flat response $g(\tau) = 1$ (i.e. no multiple rejection). The inverse Radon transform $u_U(\tau,p)g(\tau) \to \widetilde{u}_U(t,z)$ yields the upgoing wave field $\widetilde{u}_U(t,z)$ without receiver-ghost multiples.

Secondly, a predictive deconvolution is used to eliminate the near-offset source ghosts in a common-receiver gather. The prediction distance is expressed in terms of the two-way vertical traveltime in the water layer.

Finally, we apply the classic Radon velocity filter to remove other multiples based on the residual moveout (Foster and Mosher, 1992). The required velocities are obtained from VCS velocity analysis described bellow.

3. Velocity analysis and NMO correction

Due to its unique acquisition characteristics, VCS requires a special way of obtaining a reasonable velocity function compared to surface data. Referring to Figure 1, we consider the source S and the receiver G at the cable O over a single interface. By analogy with the VSP-CDP transform, the reflection traveltime is expressed in terms of the offset x and velocity v as follows:

$$\begin{aligned} t &= \frac{1}{v}\sqrt{x^2+(2H-h_0)^2} \\ &= \sqrt{t_0^2 - \frac{h_0 t_0}{v} + \frac{x^2+h_0^2}{v^2}}, \end{aligned} \tag{3}$$

where $t_0 = \frac{2H}{v}$ is the two-way vertical traveltime, H the depth of the reflector, and h_0 the depth of the receiver. Equation (3) is used for velocity analysis and NMO correction of VCS data. In addition, a DMO-type correction is required to account for the presence of dip.

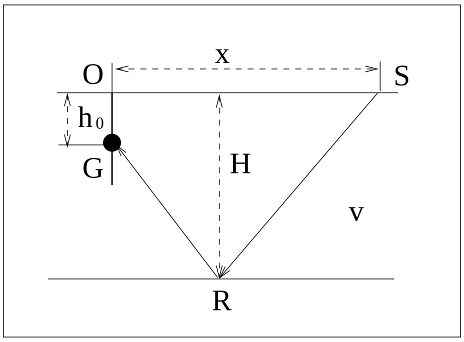

Figure 1: VCS geometry. S, R and G indicate the source, reflection point and receiver locations, respectively. O denotes the cable location.

4. Zero-offset time migration

To examine the impact of multiple suppression on VCS imaging, we apply a Kirchhoff time migration to NMO-corrected common-receiver sections. This is the same as standard poststack migration with surface seismic data.

Real data example

We apply this procedure to a field VCS data set from the North Sea (courtesy of Texaco). The data set was recorded by 12 live cables in a four by three rectangle with 800m interval between each cable. There are 16 hydrophones in each cable with a separation of 25 feet. The source coverage in each swath is 5600 × 5600m^2, the shot spacing is about 25m.

Figure 2 shows a common-receiver gather in a 2-D shot line which is near the cable location, the upgoing wave section after wave field separation and the result of multiple suppression. It appears that water column multiples are so strong that we can not see any primaries from the original sections (Figure 2a and 2b), this is because the water depth is only 136m at the cable location. After multiple suppression, the energy of multiples are almost disappeared and primaries can be identified (Figure 2c).

Figure 3 shows the results of velocity analysis on this common-receiver gather. For the raw data, the multiples interfere with the primaries which degrades both the vertical and horizontal resolution of the semblance plot. After multiple suppression using the proposed method, the resolution of the semblance plot is greatly improved and it becomes possible to pick a reasonable stacking velocity function (Figure 3b). We also display the results of NMO correction and zero-offset migration applied on the raw and processed data in Figures 4 and 5, respectively. Comparison of these plots shows that the effects of multiple removal are very clear both on NMO correction and migration sections.

Conclusion

We have developed and tested a special processing flow for VCS data. This includes wavefield separation, multiple suppression, velocity analysis, and zero-offset migration after moveout correction. Real data examples indicate that this flow is effective for multiple attenuation on VCS data, and it improves the quality of VCS migrated sections.

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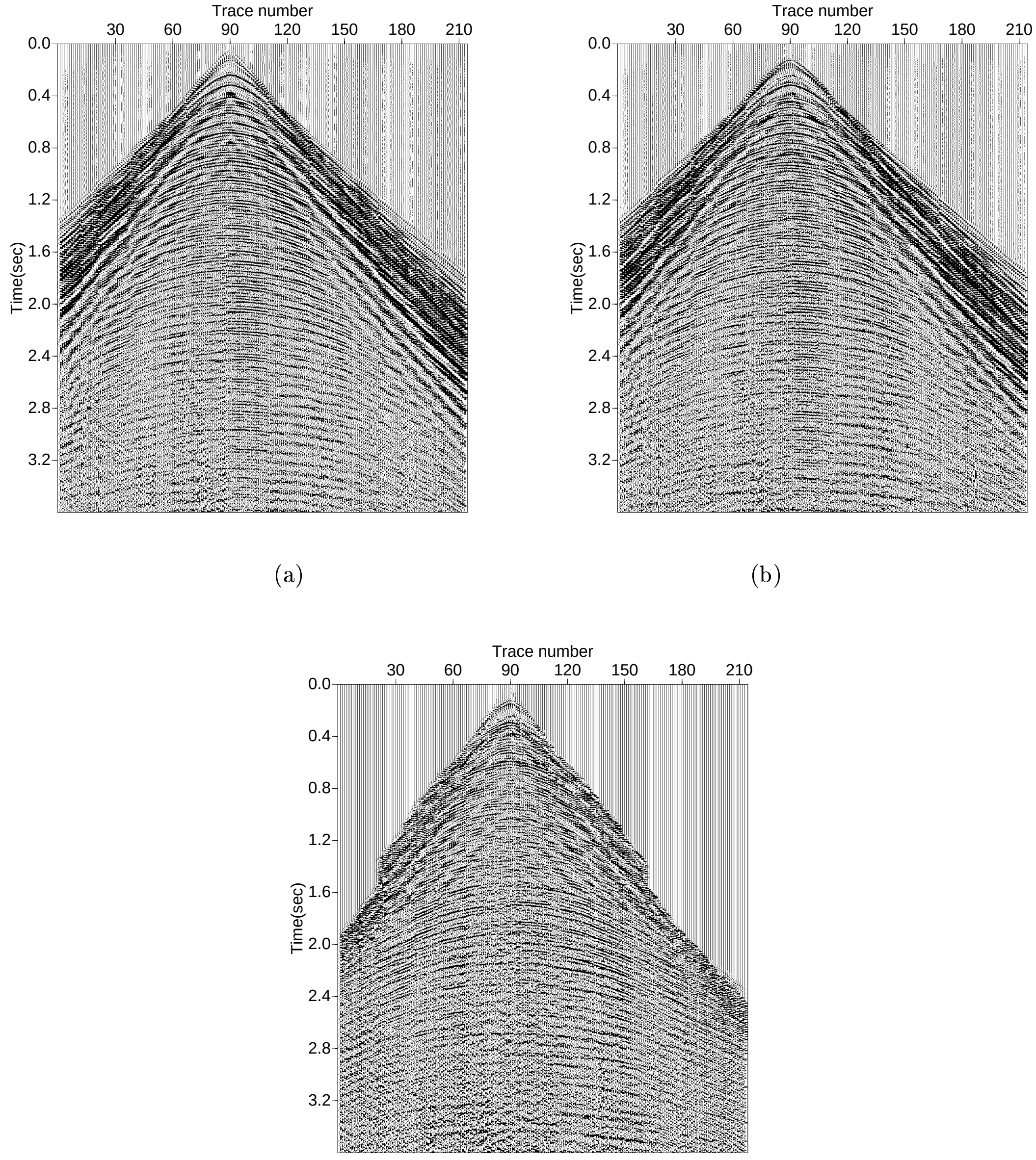
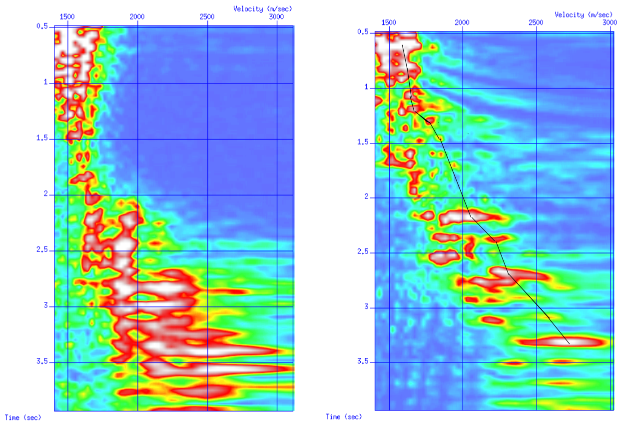


(a)

(b)

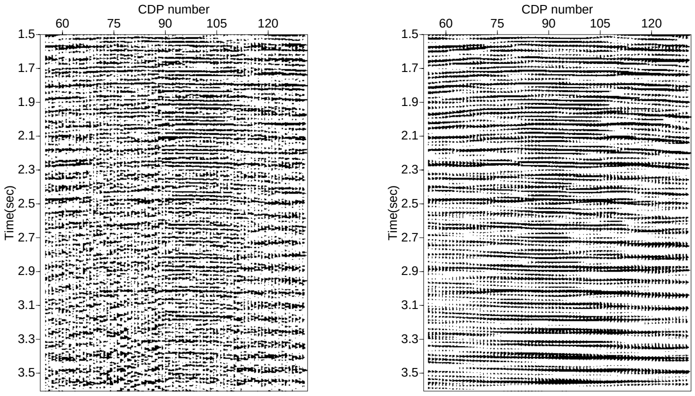
(c)

Figure 2: Single common-receiver VCS gather: (a) raw data, (b) upgoing waves with multiples, and (c) upgoing waves after multiple suppression.



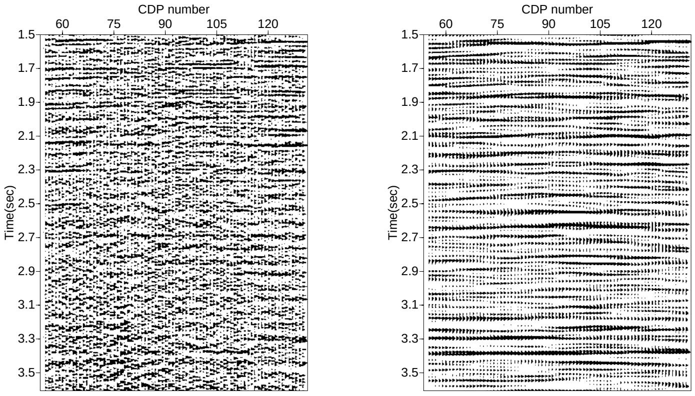
(a) (b)

Figure 3: Velocity semblance plots for the common-receiver VCS gather: (a) raw data and (b) processed data.



(a) (b)

Figure 4: (a) NMO correction and (b) zero-offset migration for the raw data.



(a) (b)

Figure 5: The same as in Figure 4, but for the processed data.