Multiple suppression in vertical cable seismic

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Summary

We present a special preprocessing scheme to attenuate multiples in vertical cable seismic (VCS). This scheme takes the advantage of the VCS technique to record both upgoing and downgoing waves. In the first stage, a common-shot (t-z) filter is applied for wave field separation. Next, a new common-shot demultiple filter removes receiver ghosts by using the amplitude ratio of upgoing and downgoing waves in the (tau-p) domain. This filter does not assume a periodicity of multiples. Neither velocity model nor source signature are required. Finally, we use the classical Radon velocity filter to remove any residual multiples on the common-receiver gather. Synthetic and field data examples demonstrate the proficiency of the method.

Introduction

In the VCS acquisition, hydrophone cables are suspended vertically in the water column, and source boats circle around the cables to obtain multi-azimuth data volumes. This technique has been used successfully for imaging complex structure due to improved data quality and uniform distribution of azimuths (Havig, 1996; Leach, 1997; Ikelle and Wilson, 1999). However, removal of multiples from VCS data is still an essential preprocessing step before migration. Existing techniques for multiple suppression require either the knowledge of a subsurface model or assumptions of the presence of distinguishable characteristics between primaries and multiples.

Here utilizing the unique acquisition characteristics of VCS, we develop a demultiple filter in the (tau-p) domain to attenuate receiver ghosts after upgoing and downgoing wave field separation, which is performed by a differential equation-based filter in the (t-z) domain (Wang *et al.*, 1999). This substantially improves the results of velocity analysis, and a Radon-based velocity filter (Foster and Mosher, 1992) may then be used subsequently for further improvements.

Receiver-ghost attenuation

For a common-shot VCS data set $u(t, z)$, the downgoing wave field $u_D(t, z)$ and the upgoing field $u_U(t, z)$ can be obtained by wave field separation (step 1). Assuming that the vertical receiver array is fixed to the sea bottom ($z = h$), $u_U(t, h)$ and $u_D(t, h)$ have the same arrival time $t = \tau$. We define 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

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

where $\Delta\tau$ is the time sampling interval. Next, we introduce the following form of the Butterworth gain function in the (tau-p) domain

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

where ϵ is the multiple rejection parameter ($\epsilon \geq 1$), and n is the parameter used to control the smoothness of the filter with value between 6 and 8. Following Zhou and Greenhalgh (1991), this function is applied on a pixel by pixel basis to the data $u_U(\tau, p)$. We have $g(\tau) \ll 1$ where high-amplitude events (multiples) are present in the data $u_D(\tau, p)$ and $g(\tau) \rightarrow 1$ 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 $u_U(\tau, p)g(\tau) \rightarrow \tilde{u}_U(t, z)$ yields the upgoing wave field $\tilde{u}_U(t, z)$ without receiver-ghost multiples.

Synthetic data example

Firstly, we examine the method on the synthetic shot gather shown in Figure 1a. The velocity model used has two horizontal layers. The P-wave velocities are $V_1 = 1500m/s$ (water) and $V_2 = 2500m/s$ (sea-bed sediments). The layer thicknesses are $h_1 = 140m$ and $h_2 = 360m$, respectively. In this example, five upgoing and downgoing waves are recorded (Fig.1a). Multiple suppression after wave field separation in Figure 1b yields only two upgoing primaries (Fig.1c).

Figure 1: VCS multiple suppression with synthetic data: (a) input data, (b) upgoing waves after wave field separation, and (c) result of receiver-ghost attenuation.

Real data application

We also apply this method to a field data set from the North Sea. Since the water depth is only about $140m$ and the geologic structure is relatively flat, interference of primaries and multiples is observed. Figure 2 shows a common-shot gather (input data) and the results of multiple suppression in the time window $0 \sim 2.0s$.

To evaluate the whole processing flow, we construct the velocity semblance plots in Figure 3 for a common-receiver gather. In Figure 3a (raw data input), it is difficult to pick stacking velocities corresponding to primaries. After receiver-ghost attenuation and Radon velocity filtering (Figures 3c), the resolution of the semblance plots is greatly improved and it is easy to pick a reasonable stacking velocity function from Figure 3c. The results of combining the receiver ghost attenuation with Radon velocity filtering are better than those of Radon velocity filtering only (Figures 3d).

Conclusions

We have developed and tested a preprocessing scheme for multiple attenuation in prestack VCS data. This technique removes free-surface multiples and improves the performance of conventional methods such as predictive deconvolution and Radon velocity filtering.

Figure 2: VCS multiple suppression with field data: (a) input data, (b) outgoing waves, and (c) result of receiver-ghost attenuation.

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(a)

(b)

(c)

(d)

Figure 3: Velocity semblance plots for a common-receiver gather: (a) raw data, (b) upgoing waves, (c) receiver-ghost attenuation and Radon velocity filtering, and (d) Radon velocity filtering only.