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Geophone noise attenuation after dual sensor summation for ocean bottom data in the wavelet domain

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Summary

In ocean-bottom seismic data acquisition, hydrophones and geophones are embedded together in the sensors and placed directly on the ocean floor. The two types of sensors detect signals of the same polarity for upgoing waves, but of opposite polarity for downgoing waves. The combination of the two sensors (hydrophone and vertical geophone) has long been used for attenuating receiver-side ghosts and water-bottom free surface multiples. One well-known challenge for dual sensor summation of ocean bottom data is the geophone noise (often referred as *Vz* noise or shear noise). This noise typically contaminates the vertical geophone component, but usually is very weak or not observed on the hydrophone component. Strong geophone noise can significantly degrade dual sensor summation and subsequent imaging results. In this paper, we propose a method to attenuate the geophone noise after dual sensor summation. Geophone and hydrophone data are first combined to obtain initial upgoing and downgoing waves. Denoising is then performed on the downgoing waves in the wavelet domain using the hydrophone data as a reference. Finally, the denoised downgoing waves will be subtracted from the original hydrophone data to obtain enhanced upgoing waves. The proposed method is successfully demonstrated on a field data example.

Introduction

In ocean bottom cable (OBC) and ocean bottom node (OBN) seismic data, geophone data are often contaminated by a large amount of noise. But this geophone noise is usually weak or absent on the hydrophone data. It appears random on shot gathers, but is coherent and exhibits converted wave moveout on receiver gathers (Shatilo et al., 2004; Paffenholz et al., 2006b). Paffenholz et al. (2006a, 2006b) showed that the geophone noise is a true measurement of the vertical movement of the ocean bottom, and is caused by body waves converting to Stoneley waves due to scattering in the shallow seabed.

Geophone noise can adversely affect the results of dual sensor summation, which is a standard and crucial step for ocean bottom seismic data processing. Various methods have been proposed to remove geophone noise in order to improve the efficiency of dual sensor summation and image quality. Shatilo et al. (2004) proposed a velocity filtering technique using the moveout differences between signal and noise in the common receiver domain. Other methods utilize the fact that the hydrophone component is not affected by geophone noise and can be used as a reference for this noise removal. Craft and Paffenholz (2007) used a multi-dimensional envelope-based matching of the geophone component with the hydrophone component for simultaneous geophone noise attenuation and wavefield separation, based on local τ-p transform and time-frequency analysis. Yu et al. (2011) developed local attribute matching of the geophone component with the hydrophone component in the multidimensional complex wavelet domain. Poole et al. (2012) proposed a geophone noise attenuation method in the 3D sparse τ-p domain by first deriving a noise model and then subtracting this noise model from the input geophone data.

In this paper, we first discuss geophone calibration and dual sensor summation, particularly in the case of deep water. Then, we introduce a wavelet-domain method to enhance the wavefield separation by attenuating the geophone noise after dual sensor summation. Finally, we present a field data example to demonstrate the effectiveness of this method.

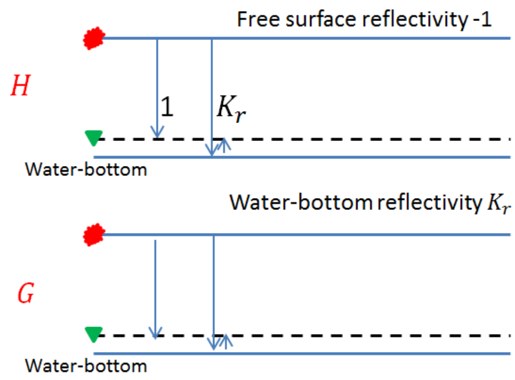

Figure 1: Considering receivers placed just above the ocean bottom, direct arrival and its upoging water-bottom multiple arrive at the same time.

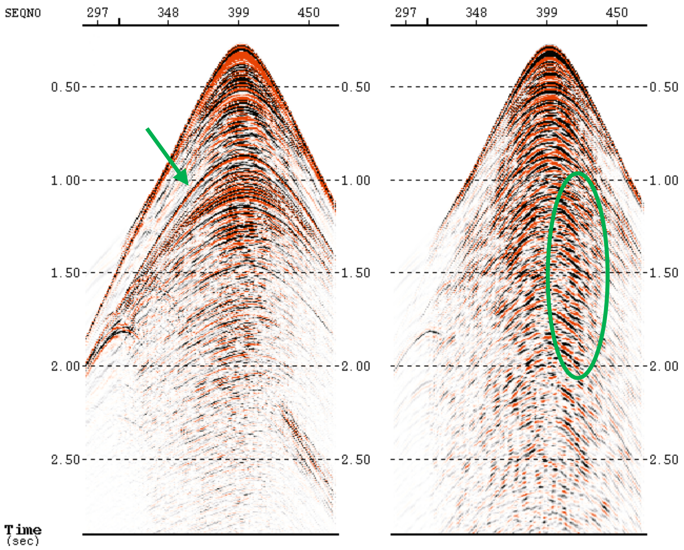

Figure 2: A commmon receiver gather of hydrophone (left) and geophone (right)

Theory

Calibration of the geophone component with respect to the hydrophone is a necessary prerequisite for dual sensor summation. It is designed to remove any inconsistencies between the two components due to differences in instrument response and/or variations in sensor coupling (Soubaras, 1996; Melbø et al., 2002; Muijs et al., 2007). Brunellière et al. (2004) and Wang and Grion (2008) summarized various calibration methods using different data windows.

In this paper, we use the direct arrivals to derive the geophone calibration filter, and then perform dual sensor summation. In ocean bottom seismic data, downgoing waves are reflected upward immediately when they reach the ocean bottom, so the downgoing waves and the reflected upgoing waves arrive at the receivers at the same time since receivers are placed on the ocean bottom. Similarly, the direct arrival completely overlaps the ocean bottom primary, as shown in Figure 1. In Figure 1, H and G represent the hydrophone recording and geophone recording, respectively. We assume the direct arrival recorded by the hydrophone is with unit amplitude, the water surface reflectivity is -1, and seabed reflectivity is K_r. In the window containing only direct arrivals, without considering the arrival angle and the wavelet difference, the hydrophone and geophone recordings are as follows:

$$H = 1 + K_r, \tag{1}$$

$$G = (-1 + K_r)/(\rho_0 \alpha_0), \tag{2}$$

where ρ_0 and α_0 are the density and velocity of water, respectively.

The scalar that matches G to H will be:

$$s = -\rho_0 \alpha_0 \frac{1+K_r}{1-K_r}. \tag{3}$$

Note that this scalar is the negative of the scalar derived by Barr and Sanders (1989). Therefore, after applying this scalar to the geophone, we can obtain the upgoing waves by subtracting the geophone data from hydrophone, and the downgoing waves by summing the two. In order to calibrate both the amplitude and phase of the geophone with respect to hydrophones, we use a calibration filter f_c instead of a scalar to match the geophone data to hydrophone data in the selected window. The calibration filter f_c is solved by minimizing the following objective function in the window containing only direct arrivals:

$$\mathrm{E} = \sum \| H - f_c * G \|^2 \tag{4}$$

The upgoing and downgoing waves are then calculated as follows:

$$\mathrm{U} = (H - f_c * \mathrm{G})/2, \tag{5}$$

$$\mathrm{D} = (H + f_c * \mathrm{G})/2. \tag{6}$$

Like previous methods, we assume that hydrophone data are free of geophone noise, and we use the hydrophone data as a reference to remove geophone noise. Considering that downgoing wavefields are contaminated with geophone noise and contain no primary energy, we compare the downging wavefields with the hydrophone data in a multidimensional domain, and use thresholding to reject noise on the downgoing component. Using the downgoing wavefields after dual sensor summation can minimize the risk of damaging primaries since no primary energy is contained in the downgoing wavefields (Poole et al., 2012). We choose the 2D dual tree wavelet transform (Selesnick et al., 2005; Yu et al., 2011) to facilitate better signal-noise separation. The proposed workflow is as follows:

1. Apply the 2D dual tree wavelet transform to the hydrophone data and downgoing wavefields;
2. Compute (sample by sample) ratio r of the amplitudes (downgoing wavefields/hydrophone) in the wavelet domain.
3. Use the amplitude ratio r to reject noise in the downgoing component by setting a threshold σ_H:

$$D' = \begin{cases} D, & r \le \sigma_H \\ 0, & r > \sigma_H \end{cases} \tag{7}$$

4. Apply an inverse 2D dual tree wavelet transform to the denoised downgoing component;
5. Subtract the denoised downgoing component D' from the hydrophone data H to obtain the denoised upgoing component U'.

Examples

Figure 2 shows an example of an ocean bottom node receiver gather where the water depth is 451 m, with hydrophone on the left and geophone on the right. Figure 3 shows the upgoing waves (left) obtained using equation 5, and the downgoing waves (right) obtained using equation 6. We can see that the downgoing ghost of direct arrivals (pointed by the green arrow) are removed from the upgoing component. However, the upgoing waves are contaminated with geophone noise (green oval), which is not present on the hydrophone data (Left of Figure 2). We can see similar pattern of the geophone noise in the downgoing component. The upgoing and donwgoing waves after dual sensor summation look more like the geophone data.

Next we use the workflow described in the previous section to obtain the denoised downgoing component, which is shown on the right panel of Figure 4. Compared with the initial downgoing waves on the right panel of Figure 3, we can see that the geophone noise has been mostly attenuated. By subtracting the denoised downgoing component from the hydrophone data, we obtain the denoised upgoing component as shown on the left panel of Figure 4. Compared with Figure 3, we can see from Figure 4 that the denoised upgoing component more closely resembles the hydrophone component. This is also confirmed by the FK spectrum comparison in Figure 5 (compare left and right spectra).

Conclusions

We have proposed a method to attenuate geophone noise after dual sensor summation. The geophone and hydrophone are first combined to obtain upgoing and downgoing waves. We then use hydrophone data as a reference to reject noise on the downgoing component in the multidimensional wavelet domain. The denoised downgoing waves are then subtracted from the hydrophone data to obtain the final denoised upgoing waves. The proposed method is successfully demonstrated on a field data example.

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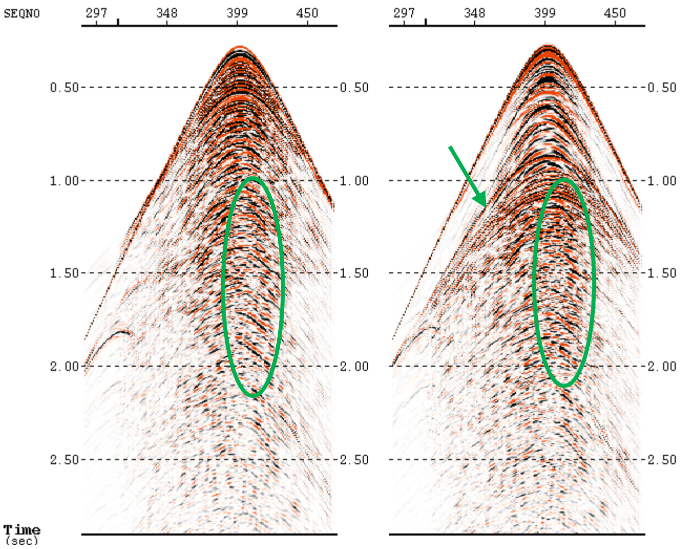

Figure 3: Upgoing (left) and downgoing (right) after dual sensor summation.

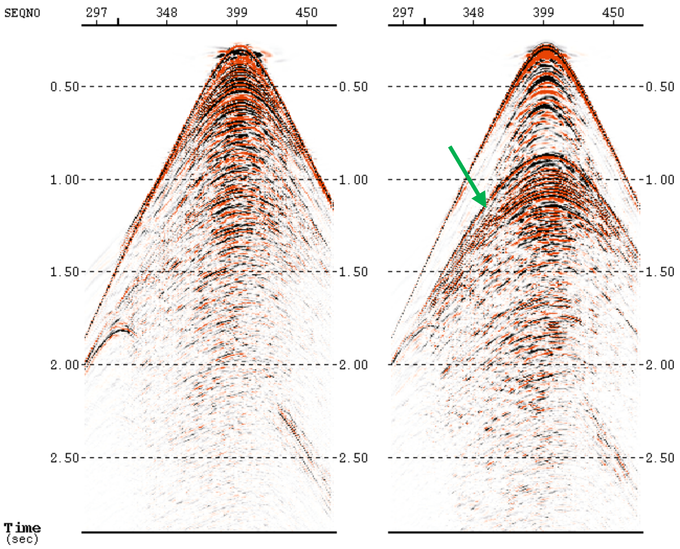

Figure 4: Upgoing (left) and downgoing (right) after dual sensor summation and geophone noise attenuation.

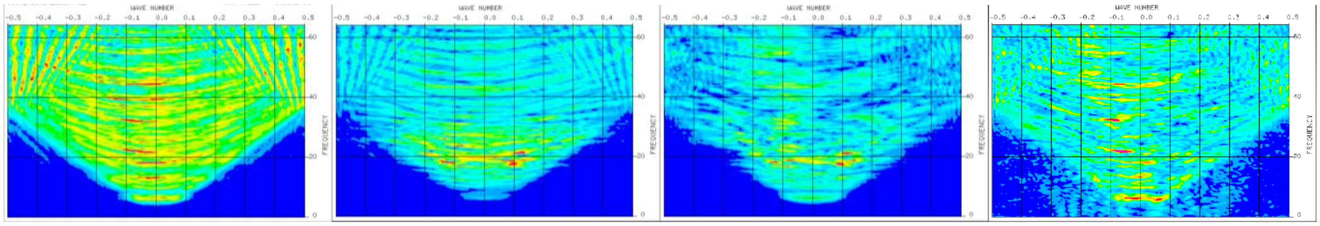

Figure 5: From left to right are the FK spectrums of hydrophone, geophone, upgoing waves without geophone noise attenuation, and upgoing waves with geophone noise attenuation.

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