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Increasing signal-to-noise ratio of marine seismic data: A case study from offshore Korea

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ABSTRACT

Subsurface imaging is difficult without removing the multiples intrinsic to most marine seismic data. Choosing the right multiple suppression method when working with marine data depends on the type of multiples and sometimes involves trial and error. A major amount of multiple energy in seismic data is related to the large reflectivity of the surface. Surface-related multiple elimination (SRME) is effective for suppressing free-surface-related multiples. Although SRME has some limitations, it is widely used because it requires no assumptions about the subsurface velocities, positions, and reflection coefficients of the reflector causing the multiples. The common reflector surface (CRS) stacking technique uses CRS reflectors rather than common mid-point (CMP) reflectors. It stacks more traces than conventional stacking methods and increases the signal-to-noise ratio. The purpose of this study is to address a process issue for multiple suppression with SRME and Radon filtering, and to increase the signal-to-noise ratio by using CRS stacking on seismic data from the eastern continental margin of Korea. To remove free surface multiples, SRME and Radon filtering are applied to attenuate the interbed multiples. Results obtained using synthetic data and field data show that the combination of SRME and Radon filtering is effective for suppressing free-surface multiples and peg-leg multiples. Applying CRS stacking to seismic data in which multiples have been eliminated increases the signal-to-noise ratio for the area examined, which is being considered for carbon dioxide capture and storage.

1. Introduction

One of the major tasks in seismic data processing is attenuating the multiples in recorded data, which are included in most seismic reflection data. Without proper treatment for multiples, it is hard to interpret seismic reflection data meaningfully. It is especially important for a high resolution velocity spectrum to pick accurate velocity (Ebrahimi et al., 2016; Gan et al., 2016). Normally, the multiples consist of free-surface multiples and internal multiples. Free-surface multiples have at least one downward reflection. For internal multiples, all downward reflections occur below the free surface. Although primary reflections and multiples could have information about the subsurface, the primary reflections are typically considered the signal, and multiples are considered a kind of coherence noise to be eliminated. Accordingly, various methods have been developed to attenuate multiples. To remove free-surface multiples, predictive deconvolution (Peacock and Treitel, 1969), wave-equation-based prediction (Bernth and Sonneland, 1983; Berryhill and Kim, 1986), and the Radon transform (Thorson and Claerbout, 1985; Hampson, 1986) are widely used.

One type of method used for the elimination of internal multiples uses the differences in characteristics of primary reflection and multiples. The other type predicts and subtracts multiples from seismic reflection data based on ray theory (Hardy et al., 1990; Keydar et al., 1998; Weglein, 1999). Characteristics that can be used to distinguish the primary reflection and multiples include periodicity, moveout difference, frequency range, and phase reversal. Among these, periodicity and moveout difference are most frequently used to attenuate multiples. The methods based on the moveout difference are stacking (Mayne, 1962; Schoenberger, 1996), FK (frequency-wavenumber) filtering (Ryu, 1982), and Radon filtering. The stacking method strengthens primary reflection and weakens the multiples and high-frequency artificial noise to increase the signal-to-noise ratio. Although the stacking method can be effective, it has a disadvantage in that the amplitude of the multiple is not attenuated directly. This limitation can be overcome by FK filtering. This method is effective for suppressing peg-leg multiples for a deep water layer that has a moveout difference of more than 50 ms. However, it is disadvantageous in that the removal of multiples is incomplete in the case of near offset according to parameter settings, and low-frequency primary reflections are attenuated (Hardy and Hobbs, 1991).

Abbreviation: CCS, carbon dioxide capture and storage; CMP, common mid-point; CRS, common reflector surface; NIP, normal-incidence-point; SRME, surface-related multiple elimination.

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Radon filtering is more effective across the full range of offsets. This method utilizes velocity discrimination between the primary reflection and multiples in the tau-p domain. When the moveout difference is far smaller than 50 ms or it is not enough to attenuate strong multiples, periodicity is used instead. Predictive deconvolution is used to attenuate periodic multiples based on the assumption of zero offset. This method is more appropriate for suppressing multiples in poststack data rather than prestack data. It is especially effective at periods of 300 ms or less (Hardy et al., 1990). If the subsurface consists of flat geological structures, multiples are periodic in the tau-p domain. Therefore, predictive deconvolution in the tau-p domain can be a powerful method of suppressing multiples if the water bottom is flat (Taner, 1980; Lokshtanov, 1995).

Ray theory methods are used instead of the differences in characteristics of the primary reflection and multiples. Ray theory is useful when it is difficult to suppress peg-leg multiples due to insignificant moveout differences, when the periodicity is too long to eliminate multiples, or when a geological structure is too complicated to attenuate multiples using the periodicity. This method predicts multiples and subtracts them from reflection data. If the travel time and amplitude of multiples are erroneously predicted, however, the removal of actual multiples may be incomplete, or the amplitude of multiples with opposite polarity may remain in shot gather data (Hardy et al., 1990). Multiple attenuation methods using ray theory include wave equation multiple rejection (WEMR) (Wiggins, 1988), the inverse-scattering series method (Weglein et al., 1997; Ikelle, 2005), surface-related multiple elimination (SRME) (Verschuur et al., 1992; Dragoset and Jericevic, 1998), and wave extrapolation (Wiggins, 1999).

Multiple attenuation methods have advantages and disadvantages depending on the characteristics of acquired seismic reflection data. Thus, proper methods should be combined based on optimized variables that have been verified using various models for quality improvement. In the bottom part of the stack section, where the signal-to-noise ratio and the continuity of the layer boundary are poor, and common reflector surface (CRS) stacking can be applied using a hyperbolic surface instead of a hyperbola equation (Kim and Jang, 2015). Since a hyperbolic surface covers neighbouring CMP positions, more stacking folds are possible and the signal-to-noise ratio can be increased. But in the case of shallow interface reflection, the seismic resolution is decreased since the reflection coefficients become complex and induce a different phase change (Deidda et al., 2012).

In general, the CRS stacking workflow includes none of the multiple elimination methods that require data regularization, wavelet knowledge, or manual picking in the velocity spectra. However, it is possible to apply poststack SRME to eliminate multiples in the CRS stack section (Dümmong and Gajewski, 2008). Hardy and Hobbs (1991) studied a method to remove multiple reflections effectively by determining the application order of multiple attenuation methods. Huo and Wang (2009) proposed iterative expanded multichannel matching filter to improve the effectiveness of multiple elimination. Cai et al. (2009) proposed combining SRME and wavefield extrapolation to eliminate multiples in seismic reflection data from the Gulf of Mexico. Shi et al. (2010) proposed an iterative SRME method for deep water seismic reflection data. El-Emam et al. (2011) applied general free-surface multiples prediction, extended interbed multiples prediction, and deterministic interbed demultiples to onshore seismic reflection data from Kuwait. Wang et al. (2012) tried to remove shallow water multiples by cascading shallow water demultiples, followed by SRME in marine seismic reflection data. Xue et al. (2016) tried to attenuate multiples using high order sparse Radon transform. Apart from multiple elimination or CRS stack, there is iterative deblending performance for increasing signal to noise ratio (Chen et al., 2014; Zu et al., 2016).

In this paper, we apply the SRME approach by Verschuur (1991), and Berkhout and Verschuur (1997). Based on this approach, we combine SRME, Radon filtering, and CRS stacking and apply them to synthetic seismic data and field data from the Ulleung basin in the eastern continental margin of Korea. First, we briefly review the basic theory. The combination of SRME, Radon filtering, and CRS stack was validated using synthetic data, and we demonstrate its application to the Ulleung basin seismic data to show the subbottom structure. Afterwards, a comparative analysis was conducted. The results show that combining SRME, Radon filtering, and CRS stacking is an effective method for increasing signal-to-noise ratio and imaging subsurface structures in the study area.

2. Theory

2.1. SRME

Multiples in marine seismic data can be categorized into two classes based on where the downward reflections occur (Dragoset and Jericevic, 1998). One category is free-surface multiples that have a downward reflection at the water surface. The other is internal multiples that have downward reflection at the water bottom or below. Since the reflection coefficient of the water surface is far greater than that of the water bottom, the free-surface multiple is strong in the stack section, which causes confusion by making it seem that a layer boundary exists. Hence, it is important to attenuate free-surface multiples for accurate geological interpretation.

SRME predicts multiples through convolution of the measured wavefield with itself and subtraction from the input data. In situations with small or velocity differences that are difficult to distinguish between the primary reflections and multiples, SRME is very attractive because it can remove multiples effectively without affecting primary events (Verschuur et al., 1992). However, in the far offset range, SRME is not efficient due to finite aperture, directivity effects, spatial aliasing, and cable feathering. Solutions such as shot interpolation and azimuth moveout are complicated. However, multiples can be effectively eliminated by applying SRME to cases of near offset, and Radon filtering to cases of far offset (Hongtu et al., 2009).

Free-surface multiples are strong in the stack section because the reflection coefficient at the water surface is nearly −1. Fig. 1 shows the major path of the free-surface. For free-surface multiples, waves are delivered through source **S**, reflected at least once at point **M**, and recorded at receiver **R**. Thus, free-surface multiples can be predicted based on the travel time of two reflections and spatial convolution. However, since the amplitude of such predicted multiples is far greater than the actual amplitude, a cross-convolution of the path of the primary reflections $\mathbf{W_A}$ and $\mathbf{W_B}$ needs to be conducted in consideration of direct waves, multiples, and the slope of the water bottom (Hadidi et al., 2002).

Since SRME does not rely on the moveout difference, the primary reflection is not affected when multiples are removed, even if the moveouts of the primary reflection and the multiple are similar. The free-surface multiple can be described by the following Kirchoff integral

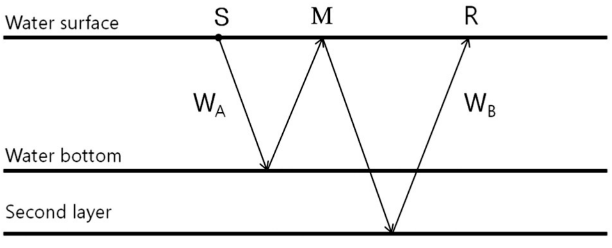

Fig. 1. Relationship between primary reflection and first-order surface multiple.