Commun. Comput. Phys.
doi: 10.4208/cicp.OA-2018-0074

Vol. **28**, No. 1, pp. 128-140
July 2020

Making True Amplitude Angle Domain Common Image Gathers Using Invertible Radon Transform

Hongwei Liu* and Yi Luo

EXPEC Advanced Research Center, Saudi Arabia.

Received 26 March 2018; Accepted (in revised version) 15 October 2018

Abstract. Converting subsurface offset domain common image gathers (ODCIGs) to angle domain common image gathers (ADCIGs) through a Radon Transform (RT) in either the spatial or wavenumber domain is efficient and valid except for the distortion of both frequency spectrum and amplitude versus angle (AVA) effect. This paper presents two modifications to the existing method to keep the frequency spectrum of the resultant ADCIGs the same as the input data and to preserve the relative amplitudes. The spectrum invariance is achieved by replacing the conventional RT or slant slack by an invertible RT. Amplitude preservation is obtained by applying an amplitude correction factor in the angle domain. Tests on both synthetic and field datasets validate the accuracy of these modifications.

AMS subject classifications: 86-08

Key words: True amplitude, ADCIG, reverse time migration, invertible Radon transform.

1 Introduction

Reverse time migration (RTM) aims to construct an image of subsurface reflectors by using recorded seismic data and migration velocity models. The images can be formed by calculating numerical solutions to the two-way wave equations based on these given conditions. While the goal of conventional migration is to produce images of subsurface structure, so-called true amplitude or amplitude preserving migration attempts to maintain relative amplitude information. As a consequence, event amplitudes in the migrated results (stacked images or gathers before stacking) become proportional to the angle-dependent reflection coefficients of subsurface reflection interfaces. Zhang and Sun (2009) showed that true amplitude RTM can provide better products for subsalt imaging and AVA analysis than those from normal migration methods.

*Corresponding author. *Email addresses:* Hongwei.Liu@aramco.com (H. Liu), Yi.Luo@aramco.com (Y. Luo)

An alternative method to estimate reflection coefficients is through seismic inversion, such as Least Squares Migration (LSM). Inversion techniques usually need several iterations to converge, while true amplitude RTM requires only one iteration. Indeed, true amplitude migration can be considered as the first iteration of least squares migration. Because only one iteration is employed, it is critical that this iteration is properly preconditioned for recovering the reflection coefficients; such pre-conditioning operators have been well established in the past several decades. Another advantage of migration over inversion approaches is the resistance to noise because no data matching is performed in the migration process. Given its computational efficiency and robustness to noise, true amplitude RTM has been, and will keep playing an important role for imaging subsurface structures and estimating medium properties.

Bleistein *et al.* (2001) derived the true-amplitude Kirchhoff migration formula, which is a by-product of his ray-based seismic inversion theory. Other researchers further developed wave-equation-based true amplitude migration methodologies, including one-way wave equation migration (Zhang *et al.*, 2005) and RTM (Xu *et al.*, 2011; Zhang and Sun, 2009). To gain leverage from true amplitude migration, many researchers have developed various methods to produce ADCIGs (Biondi and Symes, 2004; Dickens and Winbow, 2011; Luo *et al.*, 2010; Sava and Fomel, 2003, 2006; Shan and Biondi, 2008; Xie and Wu, 2002; Xu *et al.*, 2001, 2011; Yan and Xie, 2009, 2012; Yoon *et al.*, 2011; Zhang, *et al.*, 2010). True amplitude ADCIGs have been used for creating better stacked images and for revealing subtle and complex geologic features.

Among the methods used for generating ADCIGs, converting the migrated images from the subsurface-offset domain to the angle domain is an easy-to-implement approach. It can be realized by performing a conventional RT in the offset-depth domain or by radial-trace mapping in the offset-depth wavenumber domain (Sava and Fomel, 2000; 2003). However, the resultant ADCIGs may have degraded accuracy in terms of preserving the true amplitude and original frequency spectrum (Jin *et al.*, 2014; Luo *et al.*, 2010). This paper modifies the conventional RT-based method for preserving true amplitude and frequency content. We first introduce an invertible RT, which yields better frequency spectrums than the conventional RT. Then, we derive and apply an amplitude compensation factor for better preservation of the amplitude information. The effectiveness of these techniques on improving the quality of migrated images is confirmed by synthetic and field data tests.

2 Methods

2.1 Angle domain true amplitude Kirchhoff migration

True amplitude angle-domain Kirchhoff migration (Xu *et al.*, 2001) can be written as:

$$\tilde{R}(x,\theta)=\int_{x_{s_1}}^{x_{s_2}}\iint i\omega\frac{\cos(\alpha_s)\cos(\alpha_r)}{v_s v_r}A_s A_r e^{i\omega(\tau_s+\tau_r)}Q\,d\omega\,dx_r\,dx_s. \tag{2.1}$$