Computers & Geosciences 102 (2017) 68–78

Contents lists available at ScienceDirect

Computers & Geosciences

journal homepage: www.elsevier.com/locate/cageo

Case study

A practical implementation of 3D TTI reverse time migration with multi-GPUs

Chun Li, Guofeng Liu*, Yihang Li

Key Laboratory of Geo-detection, China University of Geosciences, Beijing, Ministry of Education, Beijing 100083, China

ARTICLE INFO

Keywords:
TTI RTM
GPU
Random boundary
Asynchronous streams
Shared memory

ABSTRACT

Tilted transversely isotropic (TTI) media are typical earth anisotropy media from practical observational studies. Accurate anisotropic imaging is recognized as a breakthrough in areas with complex anisotropic structures. TTI reverse time migration (RTM) is an important method for these areas. However, P and SV waves are coupled together in the pseudo-acoustic wave equation. The SV wave is regarded as an artifact for RTM of the P wave. We adopt matching of the anisotropy parameters to suppress the SV artifacts. Another problem in the implementation of TTI RTM is instability of the numerical solution for a variably oriented axis of symmetry. We adopt Fletcher's equation by setting a small amount of SV velocity without an acoustic approximation to stabilize the wavefield propagation. To improve calculation efficiency, we use NVIDIA graphic processing unit (GPU) with compute unified device architecture instead of traditional CPU architecture. To accomplish this, we introduced a random velocity boundary and an extended homogeneous anisotropic boundary for the remaining four anisotropic parameters in the source propagation. This process avoids large storage memory and IO requirements, which is important when using a GPU with limited bandwidth of PCI-E. Furthermore, we extend the single GPU code to multi-GPUs and present a corresponding high concurrent strategy with multiple asynchronous streams, which closely achieved an ideal speedup ratio of 2:1 when compared with a single GPU. Synthetic tests validate the correctness and effectiveness of our multi-GPUs-based TTI RTM method.

1. Introduction

Reverse time migration (RTM) (Baysal et al., 1983) has made great advances and has been most commonly applied to imaging complex areas, especially for subsalt and thrust belt structures. It uses a full acoustic two-way wave propagation algorithm requiring shot and receiver propagation in time, which has great advantages at handling large lateral velocity variations and steep dips or overhangs. But when anisotropy exists in numerous rocks and materials (Thomsen, 1986). Conventional isotropic RTM is insufficient for high-resolution imaging in these areas. Tilted transversely isotropic (TTI) RTM seems to have become the focus of such complex anisotropic structures.

Instead of solving the complicated anisotropic elastic wave equations in TTI media, simpler acoustic anisotropic equations have been proposed for the application of the anisotropic RTM. Alkhalifah, (1998, 2000) proposed an “acoustic assumption” by setting shear velocity (SV) to zero along the symmetry axis based on an accurate dispersion relation. The dispersion relation is a fourth-order equation derived from solving the Christoffel equations for homogeneous vertical transversely isotropic (VTI) media. Zhou et al. (2006a, 2006b), Hestholm (2007), and Duveneck et al. (2008) introduced different auxiliary wavefields and spilit the fourth-order PDE into two coupled second-order PDEs in the time domain for VTI equations. The TTI equation can be derived from the VTI equation by introducing a coordinate transformation. Zhou et al. (2006a, 2006b), Zhang and Zhang (2008), and Fletcher et al., (2008, 2009) derived different forms of the TTI pseudo-acoustic wave equation and similarly spilit the fourth-order PDE into two coupled second-order PDEs in the time domain by introducing different auxiliary wavefields. Fowler (2010) summarized these pseudo-acoustic wave equations and proved that they can be transformed into each other by performing a similar matrix transformation. However, there are some challenges in the implementation of the TTI RTM. One problem is the artifact of the SV wave for the primary (P) wave because the SV wave is coupled to the P wave for second order PDEs and simply setting the shear velocity along the symmetry axis to zero can not ensure the disappearance of an SV wave propagation in other directions (Grechka et al., 2004). To solve the problem, more attractive solutions are introduced (Duveneck et al., 2008; Fletcher, 2009; Chu et al., 2013; Zhan et al., 2013; Kim et al., 2013; Xu et al., 2014). The second problem is computational effe-

---

* Corresponding author.
E-mail address: liugf@cugb.edu.cn (G. Liu).

http://dx.doi.org/10.1016/j.cageo.2017.02.011
Received 29 January 2016; Received in revised form 9 December 2016; Accepted 14 February 2017

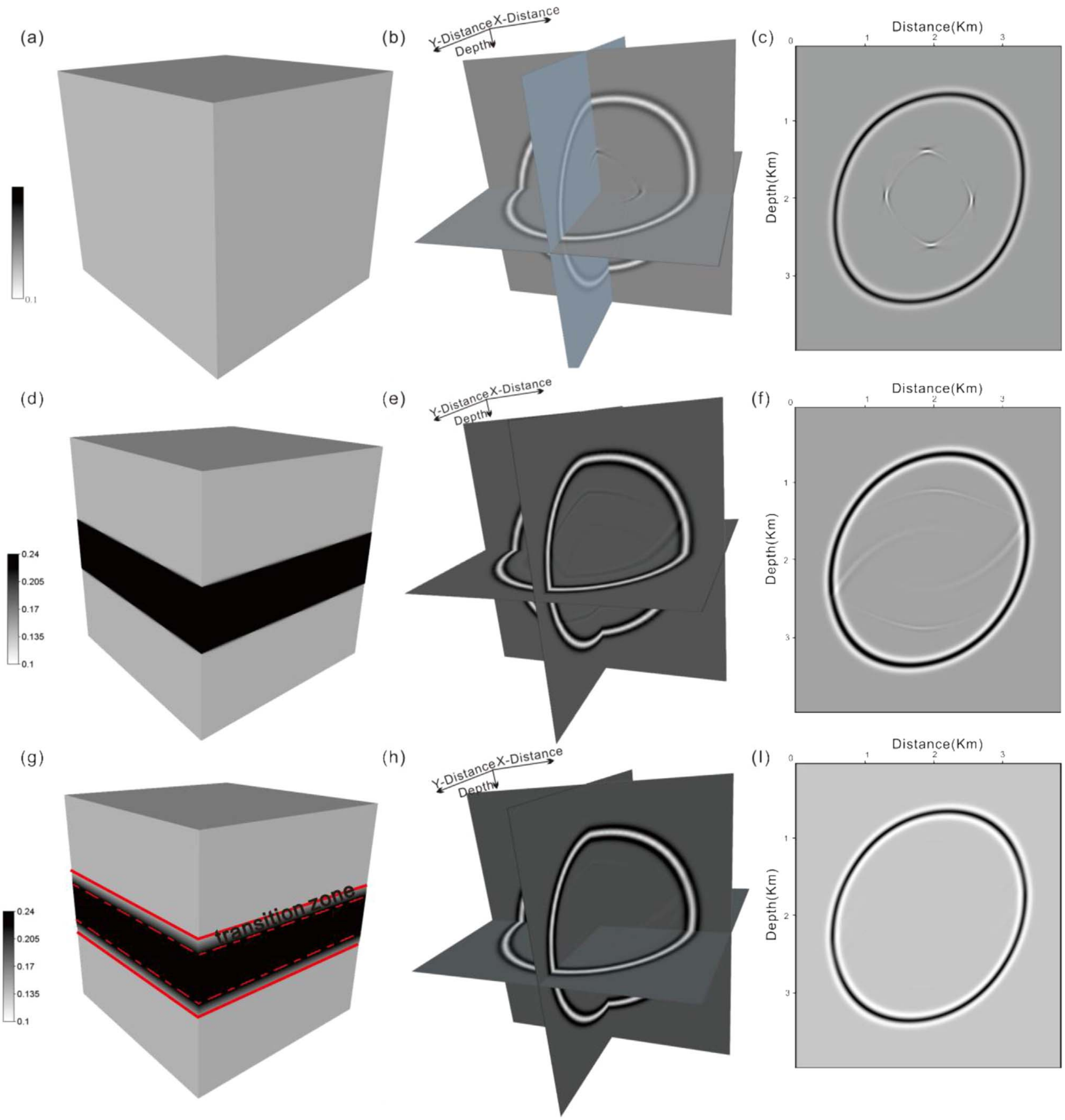

Fig. 1. Suppression of source-generated SV wave artifacts in a 3D hemogeneous TTI media (V_{pz}=2500m/s, ε=0.24, δ=0.1, θ=45°, φ=30°) using Fletcher's equation. The left panels ((a), (d), and (g)) display model parameter δ. (a) is the original model. (d) and (g) are the model with different matching way of the anisotropy parameters. The middle and right display corresponding 3D and 2D wavefield snapshots. (b) and (c) are the results without suppressing SV artifacts. (e) and (f) are the results after suppressing SV artifacts with matching of anisotropy parameters without a transition zone. (h) and (i) are the results after suppressing SV artifacts with our matching of anisotropy parameters by adding a thin smooth transition zone.

ciency. There exist mixed partial derivatives in the PDEs, which require more computation than derivatives in a single variable, especially for three dimensional (3D) operators. To speed up computation, graphic processing units (GPUs) have been developed for high-performance computing in seismic processing (Liu et al., 2013; Kim et al., 2013; Liu et al., 2015).

In this paper, we present a solution to efficiently implement TTI RTM with GPUs using the finite difference method (FD) in the time domain. Our algorithm is based on the TTI pseudo-acoustic wave equation (Fletcher, 2009). Firstly, we briefly review the theory of TTI RTM and discuss the suppression of SV artifacts. We extend the Duveneck's matching of anisotropy parameters to TTI media with setting a thin anisotropic parameter transition zone around the source. Second, we introduce random velocity boundary conditions to achieve GPU implementation. Meanwhile, we adopt multiple asynchronous streams to improve concurrency without ignoring GPU bandwidth as far as possible. Furthermore, we adopt the Peer to Peer (P2P) technologies to accelerate multi-GPUs programming with less host overhead. We also discuss the computational efficiency with our algorithm. Finally, we apply it to our model and present the correct